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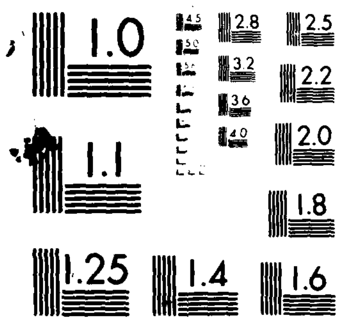

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The 1981 annual meeting of the Navy Aeroballistics Committee was held on 5-8 October 1981 at the David W. Taylor Naval Ship Research and Development Center.

This report documents the proceedings of the 1981 meeting. It contains a copy of the Committee Chairman's letter report to the Naval Air and Sea Systems Commands, the reports of significant accomplishments at the participating laboratories, summary reports of the Panels, and administrative data.

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FOREWORD

The 1981 annual meeting of the Navy Aeroballistics Committee (NAC) was held on 5-8 October 1981 at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC). The 106 participants included representatives of all agencies on the Committee, five universities, and twenty industrial contractors to the Navy. In addition, representatives of the National Aeronautics and Space Administration (NASA), the Army, and the Air Force were present as invited guests.

This report documents the proceedings of the 1981 meeting. It contains a copy of the Committee Chairman's letter report to the Naval Air and Sea Systems Commands, the reports of significant accomplishments at the participating laboratories, summary reports of the Panels, and administrative data.

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LETTER (INCLUDING RECOMMENDATIONS) TO

COMMANDER, NAVAL AIR SYSTEMS COMMAND

COMMANDER, NAVAL SEA SYSTEMS COMMAND

FROM

CHAIRMAN, NAVY AEROBALLISTICS COMMITTEE

DEPARTMENT OF THE NAVY
DAVID W. TAYLOR NAVAL SHIP RESEARCH
AND DEVELOPMENT CENTER
HEADQUARTERS
BETHESDA, MARYLAND 20084

ANNAPOLIS LABORATORY
ANNAPOLIS, MD 21402
CARDEROCK LABORATORY
BETHESDA, MD 20084

IN REPLY REFER TO:
1606:STS
5760/5420
12 Nov 1981

From: Chairman, Navy Aeroballistics Committee (NAC)
To: Commander, Naval Air Systems Command
Commander, Naval Sea Systems Command

Subj: Annual Report of the Navy Aeroballistics Committee to the Naval Air Systems Command and the Naval Sea Systems Command for the Calendar Year 1981

Ref: (a) Joint NAVAIR INST 5420.8A and NAVSEA INST 5420.11 of 28 Jun 1975

Encl: (1) 1981 NAC Recommendations
(2) Significant Accomplishments

1. In response to the requirements of reference (a), the Navy Aeroballistics Committee (NAC) held its annual meeting on 5-8 October 1981 at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC). The 106 participants included representatives of all agencies on the Committee, 5 universities, and 20 industrial contractors to the Navy. In addition, representatives of the National Aeronautics and Space Administration (NASA), the Army, and the Air Force were present as invited guests.

2. After the attendees were welcomed to the annual meeting by Dr. S. de los Santos, Mr. Lionel Pasiuk, Executive Secretary of the NAC discussed those actions that have been taken on NAC recommendations during the last five years. The panels and Committees then adjourned to their respective sessions.

3. The Committee held executive sessions on 6 and 8 October. The general session convened on 7 October, and the panels met on 5, 6, and 7 October. At the general session, panel members reported accomplishments in their various fields during the past year. Recommendations of the individual panels were reported to the Committee by the respective panel chairmen during the 8 October executive session. A social hour and banquet was held at the Tysons Corner Marriott Hotel on Tuesday evening, 6 October. Mr. Tom Clancy of DTNSRDC was the afterdinner speaker. His talk was enthusiastically received by the 115 banquet attendees.

4. The 1981 aeroballistics recommendations of the Committee to the Naval Air Systems Command and the Naval Sea Systems Command are given in Enclosure (1). The recommendations are not listed in order of priority. A summary of significant accomplishments by activities represented in the NAC is given in Enclosure (2). The voluminous panel summary reports are included in the Proceedings and will be forwarded at a later date.

1606:STS
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5. The NAC expressed concern regarding the usage, maintenance, and bookkeeping procedures being used for the Navy's high-speed wind tunnels. The hypersonic tunnel at the Naval Surface Weapons Center, White Oak Laboratory, and the 7- by 10-foot transonic tunnel at DTNSRDC were singled out. In operating these facilities, the Navy maintains a general knowledge of test techniques and capabilities. This expertise is available to increase the return on the Navy's investment in wind-tunnel testing. Recommendation 18 proposes an administrative action to take advantage of this expertise. A meeting dedicated to facilities, both existing and projected, was suggested but was not scheduled.

6. The Twelfth Navy Symposium on Aeroballistics, which was hosted by DTNSRDC on 12-14 May 1981, was evaluated as an unqualified success. To provide the necessary lead time for a similar undertaking, the Committee proceeded with plans for the projected Thirteenth Navy Symposium scheduled for the Spring of 1984. The Pacific Missile Test Center was tentatively selected as the host organization.

7. The following panel chairmen were appointed for 1982:

Panel	Chairmen
Air Inlets and Diffusers	Dr. C.F. Markarian, NWC
Gas Dynamics	*Dr. W.H. Clark, NWC
Heat Transfer	*Dr. T.F. Zien, NSWC
Launch Dynamics	Mr. K.A. Phillips, DTNSRDC
Missile Stability and Performance	Mr. L.E. Tisserand, APL/JHU
Structures and Aeroelasticity	Dr. S.L. Huang, NADC

*Reappointed

8. It was agreed that the next annual meeting of the NAC will be held at the Naval Weapons Center at a date yet to be specified. Mr. Ray Van Aken of NWC was selected to serve as NAC Chairman for 1982.

9. The Committee expressed thanks to Dr. S. de los Santos of DTNSRDC for his leadership during 1981 and to Constance A. Applegate, also of DTNSRDC, for her efficient handling of meeting arrangements.

S. de los Santos
S. DE LOS SANTOS
Chairman, Navy Aeroballistics Committee

RECOMMENDATIONS OF THE NAVY AEROBALLISTICS
COMMITTEE FOR 1981

ENCLOSURE (1)

RECOMMENDATIONS OF THE NAVY AEROBALLISTICS COMMITTEE
AT THE 1981 MEETING

1. RECOMMENDATION:

Continue to develop inviscid Euler flow codes with emphasis on the prediction of flow-fields containing regions of subsonic flow. This effort should emphasize

(a) development of efficient hybrid methods for use in three-dimensional supersonic flow-fields containing subsonic regions, and

(b) development of new computational methods aimed at achieving rapid convergence to steady state for the three-dimensional subsonic flow-fields.

BACKGROUND:

Potential flow and linearized flow assumptions have severe limitations concerning their application to missile aerodynamics at high angles of attack because of strong shocks and rotational flow. Additional problems are encountered in dealing with wing- or fin-body interactions even at moderate angles of attack. Inviscid or Euler codes are a promising method for handling these problems without going into the complexity of full Navier-Stokes equations. When the axial Mach number is supersonic, the Euler equations admit the very rapid and general marching method of solution. However, when the axial Mach number is subsonic (or is subsonic in a small region within the flow-field) this method breaks down. Existing methods for subsonic flow require some form of iterative solution and are very inefficient, requiring as many as 600 iterations for acceptable convergence.

2. RECOMMENDATION:

Experimental programs should be undertaken to determine surface pressures on the body and lifting surfaces of circular and noncircular finned configurations typical of advanced tactical missiles for Mach numbers between 3 and 8. In addition, flow-field surveys should be made to determine shock layer properties with emphasis on separated flow regions.

BACKGROUND:

In response to future tactical missile requirements, efforts are on-going to predict the aerodynamics of tactical missile configurations (e.g., circular and noncircular bodies with wings and/or fins). Data are needed for preliminary design and to validate the predictive methods.

3. RECOMMENDATION:

Improve the existing gas dynamic models for predicting rocket and ramjet plume phenomena. Specific areas that drive the ability to predict optical signatures, weapon launch interference effects and guidance interference effects, are:

- afterbody and base separation phenomena
- exit plane definition
- solid particle propagation in plumes and nozzles
- ad hoc turbulent mixing models
- Mach disk formation and location models

State-of-the-art code development and specific validation experiments are needed in all areas above.

BACKGROUND:

The Standardized Plume Flowfield (SPF) code is currently emerging for use by vehicle design and detection system specialists. This code has specific gas dynamic limitations that are currently the primary source of errors in IR, visible and UV signature predictions (i.e., attack warning range and time) and in optical guidance system interference. The most immediate needs are for the development of base effects models for incorporation with SPF, the selection of the most appropriate mixing models for use in particular plume situations, an improved Mach disk model, and the formulation and execution of validation experiments to confirm or to guide the way to improvement of the current SPF modeling. Any Navy contribution to this Tri-service program should be coordinated through the JANNAF IR and UV Tactical Missile Signatures Panel.

4. RECOMMENDATION:

Analyze data from test programs conducted in FY 80 and 81, that used scale model solid rocket motors producing representative chamber pressures and temperatures to simulate aluminized propellant boosters (e.g., SM-2, Harpoon, Tomahawk, etc.) for evaluating shipboard, ground and ship VLS platform design heating rates, erosion and protection requirements.

BACKGROUND:

Insufficient heating rate data are available to adequately define exhaust plume heat flux as a function of position in the plume or to calculate heat transfer coefficients for direct and indirect impingement of exhaust gases from solid propellant motors. In addition, some propellants are aluminized for increased performance. Impingement of this aluminized exhaust causes surface erosion which may be of more serious concern than the thermal environment. No adequate method of analyzing surface erosion of different materials exists. Analysis of structure heating and environmental protection requirements requires a method to evaluate the thermal and erosive effects of plume impingement.

5. RECOMMENDATION:

An investigation should be conducted to determine the benefits of using an ablator or insulation on the external surface of the missile structure, thereby allowing use of an aluminum structure. Application should be directed to the missile mainbody. This effort should be for high supersonic and hypersonic tactical missiles, with emphasis on solid rockets, but also including ramjets.

BACKGROUND:

An ablator or insulator on the external surface has been considered and used in past missile designs. However, a comprehensive and organized investigation has neither been undertaken nor documented on the feasibility and benefits of such thermal protection. Consequently, new innovative thermal protection concepts have not been given the attention necessary to develop them into viable candidates. With the increased consideration being given to higher speed, there is a potential for a greater payoff for the use of an external ablator or insulation to maintain the structure at a low temperature.

6. RECOMMENDATION:

A comprehensive program should be initiated to define realistic atmospheric particle erosion environments with emphasis placed on probability of occurrence and including design criteria. Fundamental parameters that need to be addressed are: rain rate, liquid water content, particle size, spatial distribution, and geographic and seasonal variation.

BACKGROUND:

A crucial factor in the design and qualification of erosion resistant aircraft and missile radomes is the definition of realistic particle erosion environments. While rain is the most commonly addressed cause of erosion; ice, snow, and dust (including that in a nuclear cloud) can also cause damage in high speed flight. The rain environment specified in MIL-STD-210B is not comprehensive enough and is too severe for random design purposes. Design criteria are needed that specify probabilities of occurrence.

7. RECOMMENDATION:

It is recommended that experiments be conducted to measure the heating rate at up to M = 4 on radome materials in an erosion-ablation environment.

BACKGROUND:

Advanced tactical missiles will encounter rain, snow, and possibly dust at Mach numbers up to 4 for approximately 30 sec. An accurate knowledge of the heating in these environments is important because the survival or performance of components like composite radomes is threatened by excessive erosion-ablation, which becomes strongly dependent on heating in the M = 2 to 4 regime. An RT/duroid 5870 radome, for example, is predicted to have almost 0.4 in. recession during an M = 4 flight through a rainstorm. The heating affects this recession prediction in two ways: (1) directly via ablation, and (2) indirectly through its effect on the temperature dependent material properties that control erosion.

However, the heating *in an erosive environment is not* deducible from current data because erosion and ablation are intrinsically coupled and the measurement of another variable is needed in order to infer both the erosion mass loss rate and the heating.

8. RECOMMENDATIONS:

Experimental flow-field data of service aircraft should be measured for use in the validation of the mathematical models used in the analytical methods currently being used for computing store carriage loads and store separation predictions. Also measure air loads on the store.

BACKGROUND:

Analytical methods are increasingly being used in the prediction of store-carriage loads and store-separation predictions to reduce the need for expensive full-scale flight tests and wind-tunnel tests. These analytical methods use a mathematical model to represent the aircraft in the calculation of flow-field interaction between aircraft and store. At present, many or most of the aircraft mathematical models used have not been checked for accuracy due to the lack of the experimental flow-field data required for validation. Due to the increasing use of aircraft mathematical models (math-models) in these and other aerodynamic prediction methods, the need for data to be used in the validation of the aircraft math-models is becoming more and more important.

9. RECOMMENDATIONS:

Support studies to determine, from experimental data, the local flow influence coefficients of one store for use in estimating the influence coefficients for another similar store.

BACKGROUND:

Extensive experimental data files exist of store-aircraft Captive Trajectory Wind-Tunnel Store separation tests of many current stores and aircraft. Methods have been investigated which show promise in the estimation of local flow-field influence coefficients from data for one store that may be useful in the estimation of the influence coefficients for a second store. Further development of these methods may provide means of using an existing databank for determing influence coefficients for a future store shape. This would extend the usefulness of the existing influence coefficient databank and decrease the need for extensive tests of new stores in the wind-tunnel captive trajectory systems.

10. RECOMMENDATION:

Develop advanced computational procedures for the analysis and prediction of flows in complex inlet-diffuser systems, including unsteady effects caused by combustor oscillations. Support experimental studies to guide and validate the numerical modeling.

BACKGROUND:

Experimental data suggest that combustor-induced pressure oscillations may feed forward into the inlet-diffuser system and drive it into unstable operation. These unsteady backpressures are known to couple with the normal shock movement in supercritical inlets, sometimes resulting in inlet nonstart.

Advanced computational procedures are very promising in their potential to model such unsteady effects and thereby permit design of inlet-diffuser systems with greater margins of stability and without significant performance compromises. It is, therefore, recommended that computational codes for the subject flows be developed, which are capable of treating practical geometries of gradually increasing complexity. Use of shock-alining adaptive grids is specially desirable to permit accurate positioning of shocks during transients. Experimental studies to guide the numerical modeling and to validate the computer codes should also be supported.

11. RECOMMENDATION:

Conduct parametric experimental and analytical investigation of the inlet by-pass concept for increasing the range of stable operation.

BACKGROUND:

A two-dimensional by-pass inlet was developed for application to the Air Force Ducted Rocket Engine Development Program. The inlet utilized a high degree of external compression combined with a relatively flat cowl lip angle which produced a strong internal reflected oblique shock. A wide "educated" slot was located on the ramp surface just inside the cowl lip to serve the dual function of an airflow by-pass system and compression surface boundary layer bleed, while acting as a shock trap for the internal reflected shock. Inlet performance was characterized by high levels of pressure recovery, relatively low drag, and a fairly wide range of subcritical stable operation. Because of these encouraging results, further development of the by-pass inlet concept is recommended.

Development effort of this concept should include a parametric investigation of the by-pass slot geometry so that design tradeoffs of by-pass airflow, inlet pressure recovery, and by-pass inlet overall drag coefficient can be evaluated for various design applications.

12. RECOMMENDATION:

Support experimental and computational program directed at the understanding of boundary-layer control in supersonic-transonic-subsonic inlet-diffusion systems.

BACKGROUND:

Boundary-layer bleed systems are used to improve inlet performance. Excessive bleed can lead to an overall performance degradation because of the need to exhaust the bleed air. To design bleed systems having minimum bleed requirements, it is necessary to include effects of the inlet boundary-layer characteristics and λ-shock and boundary-layer interaction, which have a significant effect on shock losses. These shock-train losses can account for more than half of the total inlet loss. Currently, pipe-flow methods are used for loss prediction, and their applicability to realistic inlet geometries with developing boundary layers is questionable. Flow distortion and oscillations due to separation in the subsonic diffuser should also be avoided; experimental data for short diffusers with boundary-layer control are lacking.

13. RECOMMENDATION:

Establish an experimental database for determining the components of inlet drag for both tactical and strategic missile systems, which can be used to evaluate the accuracy of existing theoretical methods or to guide the development of improved predictive methods.

BACKGROUND:

Inlet drag, which is a considerable portion of the total vehicle drag, must be accurately known to evaluate properly the geometric requirements and the performance capabilities of future missile systems. During tactical ramjet operation near take-over Mach number, for example, additive, cowl, diverter, and bleed pressure drag can add up .o over 25 percent of missile-alone drag. Large uncertainty in total inlet drag can negate the design thrust margin.

The degree to which inlet drag has been measured in past wind-tunnel tests has been limited by the lack of properly designed drag balances and/or the cost of such testing. This capability must be improved and all development programs for air-breathing missiles should include inlet drag measurements to properly assess the overall performance of the inlets. These data should be added to the present database so that present predictive methods can be evaluated and improved when necessary.

14. RECOMMENDATION:

Develop and experimentally verify engineering prediction methods for the external aerodynamic characteristics of airbreathing missile configurations at arbitrary bank and control deflection angles, and to high angles of attack extending into the hypersonic regime.

BACKGROUND:

In order to meet future projected threats, the Navy is designing airbreathing missiles. Engineering prediction methods, for the development of such designs and for tradeoff studies, is nonexistent. The combination of body buildup testing, flow visualization testing, and use of computational fluid dynamics codes has made the development of such engineering methods feasible. To support these prediction techniques, the following experimental work is recommended: force and pressure measurements on hypersonic ramjet configuration models providing a wide range of external geometric shapes; flow visualization of vertical regions; and additional body buildup measurements of component effects.

15. RECOMMENDATION:

It is recommended that experimental investigations be continued, in the low subsonic region, to measure forces or pressures on missile components (body, body-wing, etc.) at constant angles of attack with crossflow Reynolds number varied from subcritical to supercritical. Suitable test models are probably in existence.

BACKGROUND:

The interest in this type of information stems from the large mismatch between the Reynolds number in subsonic tunnel testing and the full-scale Reynolds number early in launch. Typically, at a given angle of attack, the crossflow Reynolds number in the tunnel is subcritical, whereas in flight, it is supercritical. Some prominent investigators have proposed methods to calculate the Reynolds number effect on inclined configurations (at very low speeds), but there are no experimental data in the literature to evaluate their approach.

16. RECOMMENDATION:

Engineering design guidelines should be developed for the bounds of aerodynamic parameters required for optimum maneuverability performance of tactical missiles from flight control perspective. The sensitivity of these bounds should be obtained for different candidate levels of flight control system complexity.

BACKGROUND:

High performance missiles are often severely limited in their maneuverability by the inability of the flight control system to handle strongly-varying aerodynamic lateral-directional and control cross-coupling characteristics. If appropriate bounds were known and preliminary airframe designs were constrained to fit those bounds, missile airframes will be designed which are optimized both for maneuverability and controllability.

17. RECOMMENDATION:

Develop and install dynamic testing equipment in the Navy's supersonic and hypersonic wind tunnels. The equipment should embody improved model support systems, such as air bearings, gimbals, and free-flight techniques, as well as automated systems for readout of model orientation and position.

BACKGROUND:

Certain dynamic phenomena such as the "transient trim" observed in flight tests of reentry configurations, cannot be explained on the basis of static test data. In such cases, it becomes important to measure dynamic forces. The Navy's supersonic and hypersonic wind tunnels do not now have this capability.

18. ADMINISTRATIVE RECOMMENDATION:

Contracting officials should be directed to submit proposed purchases involving supersonic or hypersonic wind-tunnel tests to the Naval Surface Weapons Center (Code K24) for comment. Those involving transonic or subsonic tests should be submitted to David W. Taylor Naval Ship Research and Development Center (Code 166).

BACKGROUND:

An inadequate test program can be extremely costly if configurational changes are required late in the development schedule. Therefore, it is desirable to obtain the views and advice of in-house experts before accepting a contractor's plan for obtaining aerodynamic data.

Although different wind-tunnel facilities have overlapping capabilities, each one also has unique characteristics which may be particularly appropriate to a given set of test requirements. Contractors are not always aware of these distinctions, or they may propose to use their own facilities to enhance their profits, at the Navy's expense.

AGENCY REPORTS OF

SIGNIFICANT ACCOMPLISHMENTS

ENCLOSURE (2)

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
(DTNSRDC)

FUEL TANK JETTISON TEST FOR F-16

A test program to study the jettison characteristics of a fuel tank from the F-16 aircraft was conducted in the 7 x 10-foot transonic wind tunnel. This dynamic drop test covered eight drop conditions at Mach numbers of 0.7 and 0.9. All launches indicated safe separation characteristics.

DEVELOPMENT OF A THERMAL DISTORTION COMPUTER CODE

A finite element code to account for thermal expansion in a solid has been developed. The program is based on a two-dimensional model using a second, or higher order interpolation function in the element space that will allow a linear as well as nonlinear temperature gradient to be prescribed in a solid body.

Using this code, the hot spot in the landing deck due to the concentrated heat load, such as those generated by high temperature jet exhaust (2800°F or higher) can be readily and more realistically determined.

NONLINEAR FINITE-ELEMENT STRUCTURAL ANALYSIS USING COMPUTER GRAPHICS

A system for performing Nonlinear Finite-Element Structural Analysis in an Interactive, Graphics-Oriented computational environment has been developed. The system constitutes a network of integrated software processors, referred to as GIST, which enables the user to perform a wide variety of operations accessible through a common "command" (or "control") language. Many of these operations are actually performed by independent processors which are linked through a "global database" to behave as an integrated system.

NAVY AEROBALLISTICS COMMITTEE (NAC)

Promoting the exchange of information among naval activities, contractors to the two Commands (NAVAIR and NAVSEA) and other agencies engaged in aeroballistics work is one of the major NAC responsibilities. To this end, meetings and symposia are held. In 1981, the Center had the unusual opportunity of planning and hosting both the 12th Navy Symposium on Aeroballistics and the 1981 NAC annual meeting. Both went exceedingly well.

JOHNS HOPKINS UNIVERSITY/APPLIED PHYSICS LABORATORY
(JHU/APL)

COMPARISON OF FLIGHT AND GROUND TEST DATA -
STANDARD MISSILE, SM-2 ER, BLOCK II

Flight test data obtained on two control test vehicles in the Standard Missile, SM-2 ER, Block II program validated the wind-tunnel-based aerodynamics for the configuration and the predicted performance of the aero/control system. The aerodynamics validated included drag, trim lift, control, and yaw-roll-coupling characteristics.

HYPERSONIC MISSILE CONCEPTUAL DESIGN AND PERFORMANCE

A recent investigation has shown that a tandem-rocket booster ramjet provides greater range capability than an integral-rocket-ramjet design for the same weight, length, and volume restrictions of the Navy's vertical launch system. A further study, made to determine the effect that ramjet cruise Mach number had on material selection and weight of structural components of the missile, indicates that the weight increased gradually from M = 5 to 6, at a greater rate from 6 to 7, and at an extremely rapid rate above 7.

THERMAL SHOCK TESTS OF STANDARD MISSILE RADOMES

A Standard Missile SM-2 radome, made of Pyroceram 9606, was tested in the solar furnace to ascertain if it could withstand the thermal stress expected with Block III missiles which will be accelerated to a higher speed than Block II missiles. The radome survived these thermal stress levels and verified the use of a design value of 22,500 psi.

MODIFIED STANDARD MISSILE MR CONFIGURATION

The Standard Missile MR airframes, SM-1 MR Upgrade and SM-2 Block II, have been improved to include a higher performance propulsion system. In order to reduce stability and increase maneuverability, shorter length dorsal fins were introduced. The extensive wind-tunnel data on this configuration have been analyzed and put into a three-dimensional nonlinear aerodynamic description of the missile's characteristics over the full Mach number range, subsonic through supersonic, for use in a six-degree-of-freedom trajectory simulation.

NAVAL AIR DEVELOPMENT CENTER
(NADC)

GRAPHITE/EPOXY COMPOSITE STRUCTURES

The NADC completed the design, fabrication, and testing of a graphite/epoxy center fuselage subcomponent. This is the first application of tension-field design in composite fuselage construction and also incorporates battle damage tolerance features. Design concepts were developed for high strain damage tolerant advanced composite wings. These concepts will be the basis for second generation composite wing development.

TECHNICAL EVALUATION OF THE BQM-74C TARGET DRONE

The U.S. Navy recently completed a technical evaluation of the Northrop BQM-74C target drone, the first Navy aerial target to incorporate a fully digital avionic processor (DAP). The BQM-74C, developed to provide supersonic threat simulation for U.S. Navy Weapons System Training and Evaluation, has the capability of being launched from land, shipboard, or aircraft. The development of launch adapters to allow air launch from the A-4 and A-[illegible] aircraft, as well as separation studies and structural analysis necessary for flight certification prior to air launch, were performed at NADC. Operational evaluation of the BQM-74C is scheduled for the near future.

PERFORMANCE IMPROVEMENT OF THE AQM-37A MISSILE TARGET

In June 1981, the Navy completed an evaluation of a modified Beech AQM-37A guided missile target called the VARIANT. The basic AQM-37A was modified to incorporate some minor autopilot gain changes and to include improved static pressure sensing, high temperature bonding, and a larger vertical stabilizer for improved lateral directional stability. These modifications extended the basic performance envelope from a maximum air speed and altitude of Mach 2.0 at 70,000 ft to Mach 3.0 at 80,000 ft.

STRUCTURAL DESIGN CRITERIA FOR AIR LAUNCHED WEAPONS

The structural design criteria imposed by MIL A 8591 were compared with actual loads experienced in captive carriage on current Navy fighter and attack aircraft. It was found that, for flight maneuvers, the inertia loads criteria of the specification were not overconservative, but the air loads criteria were often overconservative.

NAVAL SURFACE WEAPONS CENTER
(NSWC)

AERODYNAMIC PREDICTION CODES

Completed were the fourth version of the approximate aerodynamic prediction code and the first version of the numerical aerodynamic prediction code. Codes are currently being documented and transferred to legitimate users.

OBTURATOR BAND DESIGN

Completed was the first version of the Obturator Band Design handbook.

BANK TO TURN CONTROLS

It was shown that, under certain conditions, bank to turn can work as well as skid to turn control. Radome boresight error slope will be included in the simulation in the coming year.

POINT DEFENSE MISSILE

The preliminary design for an advanced point defense missile concept is completed. The design indicates that performance requirements can be met within the Sea Sparrow launcher constraints.

THREE-DIMENSIONAL LASER DOPPLER VELOCIMETER

The first measurements of a three-dimensional turbulent boundary layer on a sharp cone at Mach 3 with a three-dimensional Laser Doppler Velocimeter (LDV) have been obtained at NSWC. The angle-of-attack range was from 0 to 4 deg. Measurements were made at one axial station for seven circumferential positions. Measurements include the three components of mean velocities, turbulence intensities, and Reynolds stresses. The surface shear was measured with a Preston probe.

HIGH ANGLE-OF-ATTACK FLOW FIELDS

The flow field about a model with a 3-caliber tangent-ogive nose and a 9-caliber cylindrical body has been investigated in subsonic flow at an angle of attack of 45 deg. These measurements were made with a two-dimensional Laser Doppler Velocimeter. Also included were detailed pressure measurements. Of primary interest in the investigation was the nature of the primary and secondary separation region on the body.

NAVAL WEAPONS CENTER
(NWC)

AERODYNAMIC CHARACTERISTICS OF AIR BREATHING MISSILES

A survey has been completed to evaluate inlet effects on overall missile aerodynamics. Publication of a handbook is underway.

ROCKET MOTOR COOK OFF

An analysis of the thermal response of a rocket motor in a fuel fire was accomplished. Good agreement between analytical predictions and experiment was observed. Use of an intumescent paint as a retrofit to provide thermal protection was investigated.

BIG EYE SEPARATION

An effort was undertaken to qualify the BIG EYE weapon for release from aircraft. Various "quick fixes" such as fin modification, afterbody flare, and center of gravity shift overcame previous problems.

METAL MATRIX COMPOSITE

An experimental fin consisting of a titanium honeycomb core, metal matrix titanium skin, and solid titanium was fabricated. Tests were performed to evaluate the fin strength. Results hold promise for lightweight strong missile components.

PACIFIC MISSILE TEST CENTER
(PMTC)

AERODYNAMIC HEATING EFFECTS ON EXTERNALLY-APPLIED REFLECTIVE SHEETING

To obtain flight test intercept data, it has been proposed to apply reflective tape to the exterior surfaces of missiles, for use with laser and IR instrumentation. As part of the PMTC feasibility study, the effects of aerodynamic heating were estimated, using simulated trajectories for AIM-7F and AIM-54A missiles. These were chosen as representative of possible candidate missiles for such applications. A PMTC digital aerodynamic heating program was used to compute the limiting thin wall and thick wall material thermal responses. Guidelines were provided on suitability of various locations on the body for such applications.

TOMAHAWK FLOW FIELD EFFECTS

Air frame flow field effects on cruise missile guidance are being investigated at the PMTC to extend missile performance. Missile performance is sensitive to complex coupling of the flow field, air data system, and the mechanization of autopilot control loops.

AIM-7F TRAJECTORY DISPERSIONS DUE TO COMPONENT DAMAGE

A study was conducted to investigate AIM-7F trajectory dispersions caused by certain types of component damage. The PMTC AIM-7F digital trajectory simulation was employed in the study. The trajectory code was modified to introduce anomalies corresponding to four types of damages at prescribed ranges from the (stationary) ground target. All cases studied were air-to-surface missions, launched at subsonic speeds and at two launch altitudes and elevation angles. The normal printout was supplemented by plots of desired variables as functions of time and downrange distance from the target.

AMRAAM/AIM-7M PERFORMANCE COMPARISONS

In support of an effort to determine the relative performance characteristics of the AIM-7M and AMRAAM, modifications were made to the PMTC AIM-7F digital simulation to approximate the AIM-7M guidance system. These modifications provided for the presence of a stand-off jammer (SOJ) of optional power, as a prescribed altitude and range, and at various relative aspects. The study involved the determination of the changes in the AIM-7M maximum range launch acceptability regions (LARS) with a stand-off jammer, as compared to the case with no SOJ power. Five launcher/target speed and altitude combinations were considered, with target aspect angles varying from tail to head-on, and with jammer at various relative angles to the launch line-of-sight.

FABRICATION OF THE LAU-118/A LAUNCHER

The PMTC has made a major contribution to the development of the LAU-118/A launcher by fabricating the first 18 launchers for use during the Navy's NTE and OPEVAL programs and the Air Force's IOTE program, and is providing the next 83 launchers.

PANEL SUMMARY REPORTS

1981 REPORT TO THE

NAVY AEROBALLISTICS COMMITTEE

FROM THE

AIR INLETS AND DIFFUSERS PANEL

INTRODUCTION

The Air Inlet and Diffusers Panel met at the David W. Taylor Naval Ship Research and Development Center on 5-7 October 1981. Members present reported on accomplishments in their respective activities during the past year and formulated technical recommendations for consideration by the NAC. These are reported here. The attendees were:

Mr. W.E. Anderson	United Technologies Corp.
Mr. J. Arcangeli	McDonnell-Douglas Astronautics Co.
Mr. R.W. Briley	Scientific Research Associates
Dr. E.F. Brown	Virginia Polytechnic Institute and State University
Dr. D.A. Caughey	Princeton University
Mr. J.L. Dillon	NASA Langley Research Center
Dr. J.L. East	Naval Surface Weapons Center
Mr. R. Estes	Naval Weapons Center
Dr. K. Green	Naval Air Development Center
Mr. D.E. Holeski	Pacific Missile Test Center
Mr. A.J. Karanian	United Technologies Research Center
Mr. E.J. Kremzier	Marquardt Co.
Dr. C.C. Lee	McDonnell-Douglas Aircraft Co.
Dr. G.C. [illegible]er	Boeing Military Airplane Co.
Mr. J.R. Stevens	Johns Hopkins University Applied Physics Lab
Dr. T.C. Tai (Chairman)	David W. Taylor Naval Ship Research and Development Center
Mr. R. Tindell	Grumman Aerospace Corp.
Dr. T.T. Yang	Clemson University
Mr. G.R. Zwernemann	Vought Corporation

DAVID W. TAYLOR NAVAL SHIP RESEAR'H AND DEVELOPMENT CENTER

T.C. Tai

EJECTOR TECHNOLOGY PROGRAM

To build the technology base for VSTOL aircraft, DTNSRDC is currently engaged in a contract with Clemson University to explore the use of a curved-wall short diffuser in thrust augmenting ejectors. The purpose of the contracted work is to identify the shortest possible ejector that achieves reasonably high performance for a given nozzle configuration. In particular, the theoretical data of thrust augmentation ratio with various lift-to-drag (L/D) values are to be established, and the tradeoff of using auxiliary ejectors as a boundary-layer control device is to be evaluated. The first year's effort (1980) involves the theoretical phase only.

A paper entitled "Rotational Flow in a Curved-Wall Diffuser Designed by Using the Inverse Method of Solution of Potential Flow Theory" was presented at the 12th Navy Symposium on Aeroballistics by Tah-Teh Yang and Francois Ntone of Clemson University. More information on the project will be reported by Dr. Yang during the panel meetings.

NAVAL WEAPONS CENTER

R.H. Estes

BLEED BYPASS INLET CONCEPTS

Bleed bypass inlet concepts are characterized by self-adjusting bleed devices (slots, doors, etc.) which trap the terminal shock to prevent unstable subcritical operation. This technique can decrease the complexity of the fuel management system and can provide a more efficient engine. Under Navy contract, United Technologies Research Center (UTRC) and The Marquardt Company (TMC) have studied this concept; their findings can be found in the reports of each group's representative.

REDUCED OBSERVABLES PROGRAM

This technology program is directed to examine the present technology base and to examine the capability to design and evaluate the performance of tactical missiles with low observability. The major emphasis is on air-to-surface missiles using body shaping and inlet location to reduce the radar cross section (RCS). The total RCS of an airbreathing missile can be dramatically reduced by reducing or eliminating the signal returned by the inlet. The Naval Weapons Center's preliminary design and analysis efforts to date have centered on physically shielding the inlet on the lee side of the vehicle using a combination of the missile forebody the large wings with dihedral, and the control surfaces. In addition, the inlets, themselves, have been mounted as far aft on the vehicle as possible and, in the case of two-dimensional inlets, have had low height-to-width ratios. Reasonable performance should be obtainable from relatively conventional two-dimensional and half axisymmetric inlets if angles of attack are kept below 7 degrees.

DOCK 18 RESEARCH FACILITY

The Dock 18 Research Facility of the Naval Weapons Center's Ordnance Systems Department became operational during the summer of 1981. The facility is to be used as an in-house research tool for propulsion system components such as fuel management systems, solid and liquid fuel combustors, ramjet inlets, gas generators, and port covers. Activities to date have included a standing detonation wave test, a titanium fire test, a solid fuel ramjet combustor parametric study, a high pressure helium system component test, and a number of on-going facility calibrations.

The facility consists of a high pressure air supply (195 ft^3, 3000 psi), a low pressure air supply (4000 ft^3, 230 psi), instrument air (120 psi), an airflow heater (2000°F nominal, 5000°F max, 1000 psi max, 15 lbm/sec), high pressure supplies of nitrogen, hydrogen, and oxygen, a pressurized water supply (230 psi), a pressurized fuel supply (40 gal., 1500 psi), and a recycling temperature controlled fuel supply (150 gal., -40°F to 140°F). Facility instrumentation consists of an HP9845 data acquisition system with a total of 59 channels (19 low voltage, 40 high voltage), a 14-track tape drive, a 34-channel oscillograph, a 12-channel sequence timer, a PDP-11 computer with up to 4 output channels and 16 input channels, up to 30 amplifier-signal conditioners, a Schlieren system, and a color video tape system. The special test equipment specifically designed for testing small-scale inlets (~2.5-in. diameter), combustors, and nozzles consists of three fixed nozzles (M=2.5,3.0,3.5), a calibrated throttle, and an ejector for simulating high altitude conditions. Run times on the order of 30 sec to 3 min should be attainable without the use of the ejector.

NASA LANGLEY RESEARCH CENTER

J.L. Dillon

AERODYNAMIC CHARACTERISTICS OF AIRBREATHING MISSILE CONFIGURATIONS

In 1977, NASA Langley Research Center developed a parametric model series that could be configured to cover a wide range of airbreathing missile configurations. This model series, which included single and twin axisymmetric and two-dimensional inlets, has been tested with internal flow in the Langley Unitary Plan Wind Tunnel and in the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) 7 ft x 10 ft Transonic Tunnel without internal flow. Most recently, configuration studies have included integration of the airbreathing propulsion systems to this configuration. For medium to long range supersonic cruise missiles, this configuration provides excellent stability and control, as well as good stealth characteristics. In order to expand the technology base on this configuration class, a blended version has been developed with more wing area to provide better L/D. In addition, this configuration has been designed with maximum consideration given to stealth. Wind-tunnel tests have been completed on all of the configurations shown. The test program includes shape variations not shown on this figure and a formal NASA report will be forthcoming. In addition, RCS measurements have been made on the configurations with an elliptic forebody and a top-deck inlet.

HYPERSONIC AIRBREATHING MISSILE PROGRAM

The hypersonic airbreathing missile program at NASA Langley is centered about configurations that accommodate the integration of modular ramjet and scramjet propulsion systems. For the baseline concept, the engine is nested on the underside of the fuselage in the bow shock layer considerably aft of the vehicle apex. The forebody acts as a precompression surface for the inlet airflow and the lower aft end of the vehicle acts as a high expansion ratio nozzle. Performance calculations indicate that this type of integrated engine-airframe configuration offers potentially large benefits for missiles that require high maneuverability and cruise capability at high altitudes. An effort is underway to establish the credibility of this baseline technology. The Marquardt Company has been funded to design a baseline dual-mode hydrocarbon-fueled scramjet engine. Inlet starting and aerodynamic performance tests are proceeding at Langley.

The aerodynamic configuration spectrum has recently grown to include chin-inlet, wave-rider, and parasol-wing concepts. Also, the formulation of a cooperative inlet program effort between NASA Langley Research Center and JHU/APL is being pursued.

IOWA STATE UNIVERSITY

D.A. Anderson

APPLICATION OF AN IMPLICIT SCM SCHEME TO INTERNAL FLOW

Under a grant from the NASA Langley Research Center, an implicit version of the split coefficient matrix method has been developed and applied to two-dimensional inviscid internal flow. The goal of this research is to construct finite-difference schemes which can be used for internal flows and achieve rapid convergence even in channels with very high curvature. The technique has been used to solve for flow in a one-dimensional nozzle, a two-dimensional circular 90 degree duct, and in a Stanitz elbow. The duct flows, such as the Stanitz elbow flow, are fully subsonic. Convergence is very rapid even for regions where curvature is large.

SOLUTION-ADAPTIVE GRID DEVELOPMENT

For the past two years, the NASA Langley Research Center has sponsored the development of schemes for generating solution-adaptive grids at Iowa State University. During this time, two schemes for producing grids, which move with the evolving numerical solution to a problem, have emerged, and a new technique for producing shock alining grids for use with shock capturing schemes has been produced. All of these methods work well and are of a general application, in that no essential problems prevent their application to fully three-dimensional flows. Applications of these techniques have been made to one- and two-dimensional viscous and inviscid flows. Both internal and external flows have been solved using these adaptive grid schemes.

UNITED TECHNOLOGIES CORPORATION
CHEMICAL SYSTEMS DIVISION

W.E. Anderson

SPARK PROGRAM

The Solid Propellant Advanced Ramjet Kinetic Energy (SPARK) program, sponsored by the Army Missile Command, started in September 1978. The propulsion system being developed for this demonstration effort includes a four-spoke booster grain with a rod-and-tube fuel grain. A portion of the booster grain is overcast on the rod and tube. Work accomplished to date includes verification of the flameholding limits and autoignition of the ramjet fuel with air. Regression rate and combustion efficiencies have been verified and the flight-weight hardware has been designed based on these correlations. Inlet performance required to meet the design goals has been established on the basis of wind-tunnel tests and integrated into the design. Fabrication of six unguided flight units has been completed and initial flight tests at the Eglin Air Force Base test range have been made. Preliminary to these flights, the Chemical Systems Division (CSD) has conducted a series of freejet tests of an integral rocket ramjet assembly at its Coyote Center Facility. The final test of this series demonstrated the complete combustion cycle including transition from rocket to ramjet. All contract requirements were exceeded. The initial transition flight test is scheduled for October 1981.

ADVANCED INDIRECT FIRE SYSTEM

The CSD started work in 1980 on an Solid Fuel Ram Jet (SFRJ) propulsion system for an Advanced Indirect Fire System (AIFS). This propulsion system will be launched from an 8-in. diameter gun and will be used to control the flight trajectory to ranges greater than 60 km. The CSD is conducting this work under a subcontract from United Technologies Corp., Norden Systems, which is being funded by the U.S. Army Armament Research and Development Command.

During this development effort, CSD will obtain data related to the structural capability of the fuel grain to survive the gun launch as well as data on combustion efficiency and flameholding at Mach numbers in the range of 1.8 to 2.2. The most significant achievement during the contract effort will be to demonstrate a throttling concept for the SFRJ. To this end an inlet system was developed which falls within very stringent limits of recovery, drag, and mass flow capability. Experimental wind-tunnel tests were conducted to determine the aerodynamic performance of the complete air induction system. The system uses an axisymmetric, double-cone, nose inlet with an annular subsonic diffuser and an extended transfer duct, a tube-in-hole port cover assembly, and a dump combustor inlet. To provide maximum post gun-launch performance, high combustor total pressure recovery and low external cowl drag are specified requirements. Additionally, a design prerequisite was that the complete system be capable of mating to a full-scale flightweight combustor for freejet combustion tests subsequent to the wind-tunnel test entry.

The inlet was designed for a Mach number of two and consists of an initial centerbody cone of 18 degrees half angle and a second cone of 10 degrees half angle. The tube-in-hole port cover is motorized for remote positioning and flow bypass is provided by removal of bypass duct exit covers immediately forward of the port cover assembly.

MCDONNELL-DOUGLAS ASTRONAUTICS COMPANY
ST. LOUIS DIVISION

G.T. Arcangeli

RAMJET INLET DESIGN AND ANALYSIS METHODS

As missile designs become more sophisticated, improved inlet performance and reduced inlet radar signature requirements result in increasingly three-dimensional and highly distorted inlet flow fields. The analytic techniques that are used to design these inlets must necessarily be exacting in order to accurately predict the intricate flow phenomena that are encountered. Comprehensive comparisons of the analytic predictions to measured test data of local flow field properties and overall inlet performance are required to evaluate the abilities of these techniques and to identify refinements necessary to extend their capabilities to meet the demands of future inlet designs. Extensive verifications of these detailed analytic techniques are continually performed at MDAC-St. Louis using a large database acquired in MDC polysonic wind-tunnel and freejet tests of a variety of inlet and missile configurations and flight conditions. The analytic predictions of these complex flows are in excellent agreement with the measured data.

TACTICAL MISSILE INLET TECHNOLOGY

Ramjet engines can provide the very high performance levels required in future tactical missile applications. However, because the ramjet must operate near its maximum capabilities to realize its performance potential, an accurate knowledge of the inlet losses associated with the inlet design, inlet and missile integration, and flight conditions is mandatory. There exist only a limited amount of test data for inlets of highly maneuverable air-to-air tactical missiles. Thus, additional investigations are required to provide the necessary understanding of the inlet flow field and performance responses to missile geometry. A comprehensive tactical missile inlet database was developed. Both axisymmetric and two-dimensional inlets have been evaluated. The axisymmetric inlet configurations have included an external compression inlet and a trailing shock inlet. A variable geometry two-dimensional inlet configuration has provided additional data on the effects of the amount of external compression, throat height, throat angle, and bleed geometry.

Most recently, a chin inlet tactical missile configuration was tested in the MDC Free Jet Facility to further expand the tactical missile inlet database. The effects on the inlet flow field and performance of nose bluntness and fineness ratio, inlet face wrap angle, inlet eccentricity (nose offset), rate of subsonic diffuser turning, and bleed flow rate were investigated.

INLET RADAR CROSS SECTION REDUCTION

Advances in Soviet defense systems will necessitate the development of new signature reduction devices to ensure the survivability of strategic missile systems. Techniques of reducing the head-on radar cross section (RCS) focus on strategic missiles. The inlet is the dominant contributor to radar reflections in the missile forward sector.

The MDAC-St. Louis has been investigating a variety of sophisticated techniques for reducing the inlet RCS of strategic missiles. The characteristics of these methods have been assessed with small-scale tests, at the MDAC-St. Louis High Range Resolution Radar Facility, and with full-scale tests at the MDC Gray Butte Facility. In addition, the effects of these RCS reducing devices on engine performance are also being investigated and evaluated. One concept, injecting a radar absorbing fluid into the inlet, significantly reduced the missile radar cross section. Carbon loaded foam materials were used to simulate the injection of carbon slurry fuel. The location, pattern, and size of the injection ports were investigated under independent research and development (IRAD), and optimized for minimum RCS.

SCIENTIFIC RESEARCH ASSOCIATES, INC.

W.R. Briley

THREE-DIMENSIONAL SUPERSONIC INLET VISCOUS FLOW ANALYSIS

Under contract to NASA Lewis Research Center, a numerical method for predicting three-dimensional viscous flow in supersonic inlets has been developed and is being extended. The time-averaged Navier-Stokes equations for turbulent flow are reduced to a form suitable for forward-marching solution by assuming that embedded subsonic regions near walls are thin and that the flow along the sonic line is parallel to the wall. These equations are solved using an efficient linearized block implicit (LBI) scheme. The method treats embedded shocks, boundary layer growth including bleed effects, and various shock-boundary-layer interactions. The method has been tested in two mixed-compression inlets (Mach 3.0 and 7.4) typical of current design. The predictions of shock location and wall pressure are in good agreement with experimental data. Other predictions also compare favorably with the two-dimensional method of characteristics calculations.

THREE-DIMENSIONAL SUBSONIC DIFFUSER VISCOUS FLOW ANALYSIS

Under contract to NASA Lewis Research Center, a numerical method for predicting three-dimensional viscous flow in advanced subsonic diffusers is being developed. The analysis is being developed to treat diffuser geometries having curved centerlines with offset bends and with noncircular cross-sectional shapes. The analysis is based on a primary-secondary velocity decomposition in a given coordinate system, and leads to approximate governing equations which correct an a priori inviscid solution for viscous effects, secondary flows, total pressure distortion, heat transfer, and internal flow blockage and losses. Solution of the correction equations is accomplished as an initial-value problem in space using an implicit forward-marching technique. The overall solution procedure requires significantly less computational effort than Navier-Stokes algorithms. Predictions obtained using this analysis have compared very favorably with experimental measurements for laminar flow in a curved circular pipe, and turbulent flow in a strongly curved rectangular duct. Present efforts address the prediction of flow in diffuser geometries having axial changes in cross-sectional shape and curved centerlines with offset bend. Early work on this method of analysis was sponsored by the Naval Air Systems Command.

THREE-DIMENSIONAL VISCOUS ANALYSIS OF TERMINAL
SHOCK REGION OF SUPERSONIC INLETS

Recently developed forward marching codes for supersonic and subsonic duct flows have shown considerable potential to reduce the extensive test program by making very realistic, yet inexpensive predictions of the complex three-dimensional flow in inlets. These forward marching codes are not suitable for analysis of transonic flow in view of the sensitivity of the flow to local area changes as well as downstream conditions. Yet in order to be used as an inlet design system, the user must be able to proceed from the free stream down to the engine compressor face. To link the supersonic and subsonic forward marching analyses, an analysis capable of accurately and efficiently proceeding through the three-dimensional transonic terminal shock region is being developed under contract to NASA Lewis Research Center. An existing numerical procedure which solves the three-dimensional time-dependent Navier-Stokes equations using an efficient LBI scheme is being used. Predictions of turbulent transonic flow in a constant-area circular tube have shown very good agreement with experimental measurements of surface pressure measurements. Present activity addresses the proper treatment of inflow-outflow boundary conditions for the inlet geomtry and the use of an adaptive grid to achieve adequate resolution in the region of the shock.

THE MARQUARDT COMPANY

E.J. Kremzier

DUCTED ROCKET ENGINE DEVELOPMENT PROGRAMS--AIR INDUCTIONS
SYSTEM DEVELOPMENT TASK

Under a U.S. Air Force contract, the development of an air induction system applicable to the Ducted Rocket Engine Development (DRED) program was undertaken. The development effort included a comprehensive inlet aerodynamic analysis and design, wind-tunnel model detail design and fabrication, wind-tunnel testing, data analysis, and final reporting. A two-dimensional bypass inlet (designated as Model AM149A by Marquardt) evolved as a viable candidate for tactical missile inlet application where ramjet minimum takeover Mach numbers are low. High levels of pressure recovery were achieved, particularly at low Mach numbers. The subcritical stability range was also good at low Mach numbers. Low drag was achieved during subcritical operation because of the high bypass momentum recovery, and during supercritical operation because of the low external cowl lip angle. Design of the inlet is relatively simple with no moving parts, controls, or actuators required.

BYPASS INLET INVESTIGATION FOR THE DUCTED ROCKET PROPULSION TEST VEHICLE

An inlet test was conducted by the Marquardt Company for the Hughes Aircraft Company (HAC) under Hughes P.O. 8K-808173 WFG. Results are applicable to the Air Force Ducted Rocket PTV program being conducted by HAC. The model for this test was designated as Model AM149A-II by Marquardt. Model hardware consisted of Government Furnished Equipment fabricated by Marquardt (AM149A) under the Air Force DRED program described above and was suitably modified for the AM149A-II test. The objective was to confirm whether the results of the AM149A test could be applied to the AM149A-II configuration.

Inlet performance for the AM149A-II was in general agreement with that of the AM149A for certain Mach numbers at angles of attack of 0, 5, and 10 deg. At -5 deg, however, the total pressure recovery and capture area ratio for the AM149A-II was considerably less than the AM149A inlet at all test Mach numbers. This performance deficiency is thought to be related to the external configuration changes, particularly the wiring tunnel geometry.

A second tunnel entry was then made with additional minor modifications to the AM149A-II and designated as the AM149A-III. The objective of the second entry was to perform both diagnostic and documentation testing of the DR-PTV air induction system. Testing was performed during the month of September 1981, and data analysis is presently underway.

MCDONNELL-DOUGLAS AIRCRAFT COMPANY

C.C. Lee

SUBSONIC AND TRANSONIC FOREBODY PROCEDURE

This procedure has been developed based on a relaxation solution to solve the steady-state Navier-Stokes equations using the "velocity-splitting" method. This method was selected because it is fast and economical and sufficiently rigorous to provide a practical tool for forebody design. The computational mesh is generated using Thompson's method. The governing partial differential equations are solved in successive planes of constant fuselage station. The corresponding mesh points are connected from plane to plane to construct a body-fitted mesh about the entire model. The Navier-Stokes equations are solved by successive line relaxation on a series of passes from upstream to downstream through the computation domain. At each step, the variables in a given plane of constant fuselage station are solved twice. The first solution is a sweep using implicit relaxation on circumferential lines and the second is the same technique using radial lines. Comparisons with experimental data have been conducted in 1981 and the predictions agree well with data in terms of pressure and viscous parameters.

SUBSONIC AND TRANSONIC INLET PROCEDURE

The "velocity-splitting" method has also been applied in the theoretical analysis of three-dimensional inlet development. A simplified form of this method is used to construct the computational mesh. A centroid line is defined for the entire model and a series of radial lines is constructed for each constant-fuselage plane. The corresponding mesh points are connected from plane to plane to form the computational mesh. An inviscid solution was also formulated in 1981. The solution is based on an implicit line relaxation method. Theoretical results have been compared with experimental data with good correlation.

SUBSONIC DIFFUSER PROCEDURE

In order to solve internal flows with severe boundary layer separation a new effort was initiated in 1981 to develop a rigorous solution. The basic technique is a primitive-variable relaxation scheme which is used to solve the full Navier-Stokes equations. A pressure field is assumed and velocity components are calculated from the momentum equations. A corrected pressure field is obtained by enforcing mass continuity. The momentum equations are solved again with this corrected pressure, and the entire process is repeated until the solution converges. This technique has been formulated into two-dimensional procedure in 1981, to verify its accuracy and feasibility. Results indicate that the predictions agree very well with experimental values including the cases with severe separations.

BOEING MILITARY AIRPLANE COMPANY

G.C. Paynter

INLET DESIGN TECHNOLOGY FOR STEALTHY SUBSONIC AIRCRAFT

Stealth is now a requirement for many new tactical and strategic military aircraft. A low inlet RCS is achieved by the use of radar absorbing materials (RAM) and by "hiding" the inlet and compressor face from enemy radar. Inlet configurations designed for low RCS may feature struts or ducts lined with RAM and may be integrated within the wing or fuselage structure with substantial geometry transition and offset. The existing database for the RCS and performance characteristics of various stealthy inlet concepts is inadequate. Inlets designed for low RCS may suffer substantial performance penalties unless technology is developed to design such inlets.

The Boeing Military Airplane Company (BMAC) has an on-going IR&D program aimed at developing technology for design of submerged inlets. A baseline model is being designed which features a replaceable inlet module for easy variation of inlet contours, use of a turbopowered simulator for good simulation of the inlet capture flow, bleed or blowing for boundary layer control, and model portability. Design of the model test bed and a baseline inlet will be completed in 1981. Fabrication of the test bed and baseline inlet and a checkout test of the model in the Boeing transonic wind tunnel are planned for early 1982. A parametric test and analysis program aimed at developing a high performance submerged inlet for a strategic aircraft has been proposed to the Air Force.

A coordinated effort in parallel with the test program is underway to develop a flow analysis procedure for submerged inlets. A geometry program for defining the contours of an inlet submerged in a wing has been completed. A zonal flow analysis strategy has been established which features a coupling between PANAIR, a three-dimensional full potential, and a three-dimensional parabolized Navier-Stokes procedure. Test data from the checkout test of the baseline inlet model will be used to partially validate the inlet analysis procedure. Work is presently underway to generate a computational mesh for the baseline inlet. Analysis of the baseline inlet at selected operating conditions will be completed in 1981. The BMAC has just initiat-ı a contract with the Air Force to determine the influence of a submerged inlet on the wind aerodynamics. A combined analytical and experimental program is planned, for the 1985-1988 time period, to test a submerged inlet installed in a flight demonstrator.

DESIGN TECHNOLOGY FOR SUPERSONIC AIRCRAFT INLETS AND DIFFUSERS

A joint IR and D effort with the Air Force is underway to develop supersonic inlet installations with low RCS characteristics. The concept selection phase has been completed. Two concepts, top mounted and underwing inlets, were selected. Aerodynamic and RCS models have been designed and tested to provide a final configuration selection. A proof-of-concept aerodynamic test for the underwing inlets was completed in 1980 and the test for top mounted inlets is currently underway at Arnold Engineering Development Center. An RCS proof-of-concept test for both inlet types will be completed in 1981. The objective of the program is to define RCS-performance trades for these inlet types.

Many inlet concepts with good RCS characteristics feature subsonic diffusers with offset and RAM devices. A diffuser test apparatus was constructed to provide an accurate simulation of the flow near the lip of an external compression inlet. A test of a representative inlet geometry with a rectangular-to-round geometry transition will be completed in 1981. Detailed flow survey data from this test will be used to evaluate current diffuser flow analysis procedures. A three-dimensional viscous supersonic forebody flow analysis has been developed to predict the flow environment encountered by an inlet as a function of the forebody geometry, free stream conditions, and airplane attitude. This flow analysis was developed under joint IR&D and Air Force funding. It is currently being applied to forebody geometries now being tested at AEDC.

INLET TECHNOLOGY FOR SUPERSONIC CRUISE AIRCRAFT

A joint NASA and IR&D funded effort is underway to develop inlet technology for supersonic cruise aircraft. One objective of this is to improve the inlet performance at off-design operating conditions (angle-of-attack, starting, noise abatement modes, etc.). A second objective is the development of an integrated digital control system that is fault tolerant, reliable, and cost effective. Inlet flow analyses are being developed for the inlet flow at off-design operating conditions. A zonal analysis approach is being developed for the flow of an axisymmetric mixed compression inlet at an angle of attack. A Navier-Stokes analysis is being used to predict the inlet flow during unstarted and noise abatement operating modes. The analysis development is being supported by a series of modeling and validation experiments. Detailed experimental investigations of the skewed shock-boundary layer interactions, normal shock interactions, and subsonic diffuser flow have been proposed to NASA. A large-scale mixed compression inlet was redesigned, refurbished, and instrumented to provide data for validation of the inlet flow analysis procedures and data for the control system simulation. A high speed test was completed in 1980 and a low speed test is planned for early 1982.

GRUMMAN AEROSPACE CORPORATION

R.H. Tindell

F-14/GE-F101-X FLIGHT TESTING

A flight test program to evaluate an advanced engine design installed in the F-14 Super-Tomcat was conducted this summer. This engine, the GE-F-101X, which was derived from the engine gas generator intended for the B-1 bomber program, has a greater pressure ratio and turbine inlet temperature than the TF30 which is the F-14 production engine. It produces one-third more thrust and one-quarter less specific fuel consumption. The maximum corrected airflow, however, is ten percent greater and minimum idle airflows are considerably less than the TF30 levels, thus raising questions about the high angle-of-attack maneuvering capability of the new inlet-engine system. The extreme levels of angles of attack achieved by the F-14 during maneuvering flight can exceed $\alpha = 70$ deg. The combination of this high angle of attack and the increased level of engine corrected weight flow, gives rise to serious consideration of the adequacy of inlet-engine distortion compatibility during maneuvering flight.

The test results, which included data from a forty probe total pressure rake, having high and low response instrumentation, show that inlet performance to angles of attack of $\alpha = 40$ deg is as expected, with no significant change to the pressure contours due to the increased airflow. The GE-F-101X engines could not be stalled, even with rapid engine transients, at any combination of α/β achieved. An interesting phenomenon was observed during subsonic flight at idle engine operation. This condition produced very low inlet mass flow ratios (MFR), on the order of MFR = 0.10 to 0.20, which caused a very mild but measurable inlet instability. This subsonic inlet pressure oscillation has been denoted as purr, since it is a relatively mild acoustical phenomenon made by the F-14 Super-Tomcat. The mass flow ratio at which the onset of purr and buzz occur is a single, fairly well defined, function of flight Mach number.

VERTICAL SHORT TAKEOFF AND LANDING (VSTOL) INLET SYSTEMS

A VSTOL inlet system is being developed to provide very high angle-of-attack performance. Work done under contract to the NASA Lewis Research Center has established strong effects of diffuser design that must be accounted for in the inlet lip-diffuser integration process. Our development program included a "passive" inlet system having a shallow diffuser area distribution and an "active" inlet system that has a 0.2 D_F shorter diffuser with a much steeper area distribution. The "active" system can employ diffuser blowing. Test results obtained with separation indicators at the lip and the diffuser exit showed that separation occurred almost simultaneously at both locations with the longer inlet. For the shorter inlet, without blowing, the diffuser flow separated at lower inlet angles of attack. Sufficient blowing, i.e., elimination of the diffuser interaction, improved the α-capability to that of the longer inlet.

The strong effect of diffuser design was again demonstrated during investigations of the effects of variable inlet guide vanes (VIGV). It was observed that the very presence of the VIGV assembly (β=0) at the diffuser exit substantially reduced the α-capability of the short inlet configuration. This led to testing the longer inlet with the VIGV, but the performance of this inlet was affected to a much lesser degree. The VIGV, when installed in the short inlet with the separation prone diffuser, interacted much more strongly. Recent testing of the short inlet with blowing, with and without VIGV showed no difference between them. This shows that as long as diffuser separation is eliminated, either by proper area diffusion, such as the long inlet, or by the active means of diffuser blowing, such as the short blown inlet, the inlet system performs satisfactorily and its angle-of-attack capability is governed by its lip design.

INLET-ENGINE MATCHING TECHNOLOGY

An experimental study to investigate problems and solutions in the area of inlet-engine matching, in the transonic-to-supersonic range, has been proceeding within Grumman's Advanced Development (IR&D) program. The experiments are conducted in a 15 in. × 15 in. supersonic blowdown wind tunnel and in a 28-in. slotted transonic blowdown wind tunnel, with a rectangular isolated inlet model having a 7 in.^{2} capture area. The transonic work concentrated on developing auxiliary inlets to alleviate the matching problems associated with the small throat areas of fixed ramp supersonic inlets. An alternate application is to supply extra air for high-flow engines that requires very large thrust for relatively short bursts. High-flow systems can provide very rapid accelerations, thereby reducing the normal engine size necessary to meet a mission acceleration time requirement.

Supersonic studies were conducted to establish the tradeoffs between low drag and large stable operating airflow range (buzz margin). By removing the compression ramps of the inlet model, a normal shock version of the inlet was derived to affect the minimum drag configuration. The drag penalty to provide the efficient shock system of compression ramps was then determined. Ramp configurations that allowed the highest mass flow ratios provided the lowest drag penalties, but had the smallest buzz margins. Inlet control system requirements would have to be very exacting to regulate the performance and operational characteristics of these configurations. A possible superior approach could be a bypass door, which was found to provide significant buzz margin while incurring three-fourths of the drag penalty of the variable ramp configurations.

CLEMSON UNIVERSITY

T.T. Yang

ANALYSIS OF EJECTORS WITH CURVED-WALL SHORT DIFFUSERS

A procedure for analyzing an air-to-air ejector incorporating a short curved-wall diffuser was developed. In this type of ejector not only is the overall length significantly reduced, but also the overall performance is increased because of the highly effective pressure recovery process within the diffuser. Special features for this type of diffuser are: (1) a shear flow is admitted at the inlet, and (2) a set of auxiliary ejectors is used to provide the necessary boundary layer control.

The analysis procedure considers a viscous boundary-layer flow within the mixing chamber. The diffuser geometry is obtained from the potential flow theory using an inverse procedure. It is referred to as a Griffith diffuser. The flow field within the diffuser is calculated for a rotational flow. The effect of nonuniform velocity distribution at the diffuser exit is accounted for in the analysis. Both the length of the mixing chamber and a contraction at its exit end can be used to provide optimum thrust augmentation. A separate analysis showed that the normalized vorticity should be kept below 0.8 in order to prevent deceleration along the curved-wall diffuser when shear flow is admitted at the inlet.

Parametric analysis shows that, for an ejector with (1) an inlet secondary-to-primary area ratio of 40 to 1, (2) an overall length-to-inlet diameter ratio of 4 to 1, and (3) a plenum pressure-to-inlet static pressure ratio of 2.5 to 1, a thrust augmentation ratio, ϕ, of 1.62 can be achieved provided that the secondary ejectors can accomplish a mass ratio of 4 to 1. An increase in either the pressure ratio or the length-to-diameter ratio will result in a decrease in ϕ. But a decrease in the length-to-diameter ratio will lead to an increase of vorticity at the diffuser inlet. For a given pressure ratio there is a minimum length-to-diameter ratio which satisfies the restriction imposed by the maximum vorticity requirement. The use of saturated steam as the primary fluid results in a higher ϕ value than obtainable with air at same pressure as the steam, but having the same static temperature at the inlet as that of the ambient air.

VOUGHT CORPORATION

G.R. Zwernemann

EVALUATION OF CONVENTIONAL RAMJET (ALVRJ) MISSILE RCS AND RCS REDUCTION TECHNIQUES

The objective of this study, performed under contract to the Naval Weapons Center, was to determine the radar cross section (RCS) and to evaluate inlet RCS reduction techniques for a representative ramjet missile (the Vought/NWC ALVRJ). The three phases of this study included RCS analysis of the baseline ALVRJ missile, short pulse radar testing of various configurations of the ALVRJ missile, analyzing RCS data and implications on missile mission effectiveness, and determining the survivability of the launching aircraft. Several methods of inlet RCS reduction were evaluated including the use of RAM, inlet screens, and V-shaped inlet edges, and the reduction of the number of inlets. The major conclusions of this study were: (1) inlet treatments were effective in providing 8 to 10 dB RCS reduction, (2) a missile with four inlets treated with RAM had lower RCS than a missile with two untreated inlets, and (3) a radome and seeker antenna RCS is up to one order of magnitude larger than an inlet RCS.

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY

J.R. Stevens

ADVANCED WIDE AREA DEFENSE MISSILE (AWADM) INLET DEVELOPMENT

Various inlet designs are being investigated for use with a dual-combustion ramjet engine. In this propulsion concept, a subsonic dump combustor using a small portion of the total capture inlet airstream operates as a fuel-rich gas generator which pilots a supersonic combustor using the total engine airflow. A major advantage of the dual-combustor approach is that acceptable combustion efficiency is obtained in the supersonic combustion process over a wide range of flight Mach numbers using nontoxic and nonpyrophoric liquid hydrocarbon fuels. The baseline inlet concept is an axisymmetric nose inlet and preliminary estimates of its areodynamic performance have been made. The axisymmetric annulus is split into sectors; some providing subsonic air into the gas generator and others supplying a supersonic airstream to the supersonic combustor. Kinetic energy efficiency, air capture, additive drag, cowl leading edge, and cowl external wave drag for versions of the baseline inlet concept have been estimated using internal and external flowfields that were generated using inviscid finite difference techniques. An investigation of viscous effects on inlet aerodynamic performance will be conducted using the state-of-the-art parabolized Navier-Stokes (PNS) code that has been obtained from the NASA Ames Research Center.

AIR INLETS AND DIFFUSERS PANEL RECOMMENDATIONS TO NAC

The following recommendations were generated by the panel during the meeting.

1. RECOMMENDATION:

Develop advanced computational procedures for the analysis and prediction of flows in complex inlet-diffuser systems, including unsteady effects caused by combuster oscillations. Support experimental studies to guide and validate the numerical modeling.

BACKGROUND:

Experimental data suggest that combustor-induced pressure oscillations may feed forward into the inlet-diffuser system and drive it into unstable operation. These unsteady back pressures are known to couple with the normal shock movement in supercritical inlets, sometimes resulting in inlet unstart.

Past ramjet engine developments have relied extensively upon experimental and empirical approaches which are generally expensive and usually do not provide the basic understanding of the flow processes within the combustor. New analytical tools which provide insight into the flow mechanisms within ramjet combustors are needed to reduce the cost of the development of future advanced ramjet propulsion systems.

Advanced computational procedures are very promising in their potential to model such unsteady effects and thereby permit design of inlet-diffuser systems with greater margins of stability and without significant performance compromises. It is, therefore, recommended that computational codes for the subject flows be developed, which are capable of treating practical geometries of gradually increasing complexity. Use of shock-alining adaptive grids is sperically desirable to permit accurate positioning of shocks during transients. Experimental studies to guide the numerical modeling and to validate the computer codes should also be supported.

2. RECOMMENDATION:

Conduct parametric experimental and analytical investigation of the inlet bypass concept for increasing the range of stable operation.

BACKGROUND:

A two-dimensional bypass inlet was developed for application to the Air Force Ducted Rocket Engine Development program. The inlet used a high degree of external compression combined with a relatively flat cowl lip angle which produced a strong internal reflected oblique shock. A wide "educated" slot was located on the ramp surface just inside the cowl lip to serve the dual function of an airflow bypass system and compression surface boundary layer bleed, while acting as a shock trap for the internal reflected shock. Inlet performance was characterized by high levels of pressure recovery, relatively low drag, and a fairly wide range of subcritical stable operation. Because of these encouraging results, further development of the bypass inlet concept is recommended.

Any development effort of this concept should include a parametric investigation of the bypass slot geometry so that design tradeoffs of bypass airflow, inlet pressure recovery, and bypass inlet overall drag coefficient can be evaluated for various design applications.

3. RECOMMENDATION:

Support experimental and computational program directed at the understanding of boundary-layer control in supersonic-transonic-subsonic inlet-diffusion systems.

BACKGROUND:

Boundary-layer bleed systems are used to improve inlet performance. Excessive bleed can lead to an overall performance degradation because of the need to exhaust the bleed air. To design bleed systems having minimum bleed requirements, it is necessary to include effects of the inlet boundary-layer characteristics and λ-shock/boundary-layer interaction, which have a significant effect on shock losses. These shock-train losses can account for more than half of the total inlet loss. Currently, pipe-flow methods are used for loss prediction, and their applicability to realistic inlet geometries with developing boundary layers is questionable. Flow distortion and oscillations due to separation in the subsonic diffuser should also be avoided; experimental data for short diffusers with boundary-layer control are lacking.

4. RECOMMENDATION:

Establish an experimental database for determining the components of inlet drag for both tactical and strategic missile systems, which can be used to evaluate the accuracy of existing theoretical methods or to guide the development of improved predictive methods.

BACKGROUND:

Inlet drag, which is a considerable portion of the total vehicle drag, must be accurately known to evaluate properly the geometric requirements and the performance capabilities of future missile systems. During tactical ramjet operation near takeover Mach number, for example, additive, cowl, diverter, and bleed pressure drag can add up to over 25 percent of missile-alone drag. Large uncertainty in total drag can negate the design thrust margin.

The degree to which inlet drag has been measured in past wind-tunnel tests has been limited by the lack of properly designed drag balances and/or the cost of such testing. This capability must be improved and all development programs for air-breathing missiles should include inlet drag measurements to properly assess the overall performance of the inlets. These data should be added to the present database so that present predictive methods can be evaluated and improved when necessary.

5. RECOMMENDATION:

Develop and test deployable and flush inlet concepts that are applicable to tube or gun launched missiles and as a means of inlet radar cross section (RCS) reduction.

BACKGROUND:

Tactical and strategic missiles with tube or gun launching requirements often place severe packaging constraints on the inlet design. This often necessitates the use of deployable (pop-up) on flush inlets. These inlet concepts are also attractive as a potential means of inlet radar cross section (RCS) reduction. The current database for these inlet concepts in the supersonic regime is limited and further development of the concept is needed.

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1981 REPORT TO THE
NAVY AEROBALLISTICS COMMITTEE
FROM THE
GAS DYNAMICS
PANEL

INTRODUCTION

The panel met at the David W. Taylor Naval Ship Research and Development Center on 6-7 October 1981. Members present reported on accomplishments in their respective activities during the past year and formulated technical recommendations for consideration by the NAC. These are reported here.

The attendees were:

Dr. W.H. Clark (Chairman)	Naval Weapons Center
Dr. Leroy Devan	Naval Surface Weapons Center
Mr. S. Greenhalgh	Naval Air Development Center
Dr. M.D. Griffin	Johns Hopkins University Applied Physics Laboratory
Dr. Gary Haugh	Vought Corp.
Mr. Roland E. Lee	Johns Hopkins University Applied Physics Laboratory
Dr. Jack N. Nielsen	Nielsen Engineering and Research Co.
Dr. Richard Oman	Grumman Aerospace Corp.
Dr. Jay M. Solomon	Naval Surface Weapons Center
Dr. Andrew Wardlaw	Naval Surface Weapons Center
Dr. James Xerikos	McDonnell-Douglas Astronautics Co. - West
Mr. Frederic Zarlingo	Naval Weapons Center
Dr. Edward M. Schmidt	Ballistic Research Laboratory

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

R.J. Furey

VORTEX SHEDDING AND HYDRODYNAMIC NOISE

A method for computing vortex shedding in inviscid fluids from cylindrical bodies with and without fins is being developed. A discrete-vortex technique will be applied by using analytical and numerical conformal mapping. For the actual vortex-shedding process, boundary-layer theory and techniques for Laurent-series expansions will be used, the latter for the simulation of rolling bodies. A viscous model will be developed for modeling hydrodynamic noise due to vortex shedding.

ADAPTIVE MESHING FOR FINITE ELEMENTS

Finite Element Adaptive Refinement Solver (FEARS) is an adaptive finite element solver computer program with reliable a priori estimation of the errors due to finite element modeling. The concepts and computational procedures of FEARS with regard to solving engineering problems will be extended. The possibility of extending FEARS to three-dimensional axisymmetric problems and problems with infinite domain is being assessed.

NAVAL WEAPONS CENTER

F. Zarlingo

Efforts at the Naval Weapons Center encompass a broad range of topics ranging from ramjet combustor-inlet investigations to modeling of high pressure power sources. Two studies are underway to investigate inlet-combustor interactions and oscillations. One involves an investigation of the ramjet component response to pressure disturbances and oscillations and ultimately modeling and validating these responses in all ramjet engine testing. Test equipment has been made to study the responses of various inlet designs. In a second effort, investigation of the interaction between acoustic waves and inlet shock is underway. High amplitude oscillations have been investigated which were determined by the fuel injection to inlet air Mach number ratios indicating the need to insure fuel penetration into the dump recirculation zone. Acoustic modes in the laboratory combustor have been identified as has the relationship between the inlet and combustor acoustic lengths as an important design consideration.

Combustion of boron propellants in ducted rocket type combustors has been investigated in two-dimensional windowed combustor and water-tunnel tests. Air and fuel injection momentum have been identified as most critical parameters. Water-tunnel flow tests have provided insight into an understanding of observed combustion characteristics.

An investigation of the techniques of reducing the drag of projectiles continues. Effort is concentrated on external bur ing and contouring the base afterbody. Contouring was determined to have a significant effect on the base pressure.

Laser Doppler Velocimeter (LDV) and flow visualization techniques have been employed to study the flow field in coaxial and side dump combustors. These measurements provide insight of the characteristics observed in ramjet combustor tests.

Modeling, and validation of the models, of high pressure gas storage systems have been conducted to determine the attractiveness of such systems in tactical missile blowdown pressurization power supplies. Using cold gas storage and mono-atomic gases such as helium were validated.

NAVAL SURFACE WEAPONS CENTER

J.M. Solomon, A. Wardlaw, and L. Devan

INVISCID FLOW CALCULATIONS

EXPLICIT BLUNT BODY CODE

A code for marching Euler's equations in time to a steady state solution of the axially symmetric blunt body problem has been constructed using the MacCormack predictor-corrector method applied to the (weak) conservation law form of the equations. In considering problems with highly indented shapes, application of a switching upwind or centered spatial difference operator has been found to exhibit greatly improved robustness. Very poor initial guesses can be used to achieve final solutions. This eliminates the need to deform the body shape from one with a known solution.

IMPLICIT BLUNT BODY CODE

An unsteady axially symmetric blunt body code based on the Beam-Warming time split implicit method has been developed. The code features a new formulation in which all flow variables and the unknown bow shock geometry are treated implicitly in a fully coupled manner. Time asympototic solutions to steady flow over spherical and elliptical noses have been obtained using time steps 5 to 10 times greater than the explicit CFL value without using added artificial viscosity. Attempts to apply the new implicit method to indented nose shapes (without artificial viscosity) have not proven successful.

EULERIAN MUSCL CODE

The development of an improved general purpose inviscid shock capturing method for problems involving strong shock waves is continuing. We have chosen to develop the MUSCL (Monatone Upstream - Centered Scheme for Conservation Laws) code which is a higher order Godunov scheme using upwind differences. This method is being developed for application to explosive blasts at height-of-burst above the ground, and axially symmetric supersonic blunt body problems. Applications of the method to the shock-on-ramp problem have been completed for a variety of configurations. The results show excellent agreement with experimental measurements.

SUPERSONIC INVISCID FLOW CODE FOR TACTICAL MISSILES

The development of a steady supersonic flowfield code for applications involving tactical missile configurations containing air inlets and/or wing or fin type control surfaces has been completed. The code uses the explicit MacCormack finite difference scheme applied to the weak conservation form of the equations with new procedures for treating air inlets (unchoked and adjacent to the main body) and wings or fins with sharp leading and trailing edges. Special modeling is incorporated to simulate the effect of body separation at moderate angles of incidence.

VISCOUS FLOW CALCULATIONS

IMPLICIT THIN LAYER BLUNT BODY CODE

A viscous unsteady blunt body code based on the thin layer approximation developed by Kutler et al. of NASA Ames Research Center has been adapted for calculations involving indented nose shapes. Preliminary calculations of laminar and turbulent Stanton numbers on a hemisphere cone show good agreement with measured data. Calculated and measured surface pressures have also been compared on several indented shapes. For cases featuring sharp corners, best results were obtained with inviscid models. A laminar model produced an excessively large separation region and turbulence runs did not converge. On models without sharp corners the laminar and turbulent results produced improved results over inviscid calculations.

VISCOUS FLOW OVER INDENTED NOSETIPS

A new numerical method for treating the steady viscous flow field over blunt nose shapes at supersonic flight conditions is currently under development. The basic approach is to use directly the full steady, compressible Navier-Stokes equations discretized using certain finite difference methods. The resulting non-linear discrete equations are then solved using a Newton type iteration. To resolve the various scales present in the problem a new grid generating scheme has been developed. Preliminary analysis has indicated that standard Newton iteration is not practical when considering realistic nose shapes. Alternative iterative strategies are currently under investigation.

TRANSITION AND TURBULENCE MODELING

A new single transport model for transition and turbulent flow regimes is being investigated. The beginning of transition of a laminar boundary layer on a flat plate was reasonably predicted based on the turbulence model. The computation was carried out by considering a small disturbance at a frequency of f = 30 starting from the neutral stability curve. When the disturbance was amplified by about 200-fold according to the linear stability theory, the amplified disturbance distribution was used as the initial condition for turbulence model equations to continue downstream. The beginning of transition, defined as the location of minimum skin friction coefficient, was found to be at $Re_x \approx 3.0 \times 10^6$ which is in good agreement with the measured value of $Re_x = 2.8 \times 10^6$ as reported by Schubauer and Skramstad.

WIND-TUNNEL INVESTIGATIONS

SECONDARY SEPARATION REGION OF A SLENDER BODY AT INCIDENCE

Tests have been carried out on a tangent ogive model with a nose tip fineness of three under test conditions producing laminar separation. The model was rigidly mounted and tested in a wind tunnel with a nominal free-stream turbulence of 0.1 percent. Surface pressures on the body surface were monitored at six cross sectional pressure stations using internally mounted transducers and scanni-values which insured a pressure system response on the order of 500 Hz. The crossflow velocity components were probed in several crossflow planes using a two-dimensional LDV (laser doppler velocimeter) in the backscatter mode. Tests were conducted at an incidence of 45 deg with both a sharp tip and a 10 percent spherically blunted model. Pressure data were taken at a number of different roll orientations and the model was then repositioned to roll angles producing maximum and minimum side forces. At these positions extensive flow field surveys were carried out. Velocity measurements were taken on a very fine grid near the body surface and on a coarser one farther from it. This allowed the secondary separation regions to be resolved in great detail without making the wind-tunnel runs impractically long.

INDENTED NOSE SHAPE FLOW FIELDS

An extensive wind-tunnel investigation has been completed which provides a database for use in conjunction with arbitrary nose shape flow field modeling programs. The experimental data were taken at a nominal free stream Mach number of 5. The model was instrumented with 38 surface pressure transducers along a meridian extending from the model's centerline to the model's base. Flow field velocity measurements were made at, approximately, one hundred grid locations between the model surface and the bow shock wave using a two-dimensional LDV system. Flow field density measurements were made using a pulsed ruby laser, dual plate, optical holography system. The test matrix includes six angle-of-attack positions and seven roll orientations.

HIGH PERFORMANCE HYPERSONIC MISSILES

Hypersonic wind-tunnel force and moment and surface pressure data have been obtained for a high performance conical configuration designed for moderately high lift-to-drag ratio. The force and moment data agree well with theoretical results obtained from an approximate solution for elliptic cones. However, pressure distributions are not predicted with equivalent accuracy; particularly in regions of concave cross section. The tests indicate that hypersonic vehicles might be designed for lift-to-drag ratios of four or more, thus achieving favorable payload ratios for long range missions. The efficient performance appears to depend, in part, upon interference effects in reentrant regions of the configurations.

AEROPREDICTION CODE

A rapid areoprediction program to compute static and dynamic derivatives for tactical weapons with axisymmetric bodies, under development for a number of years, was completed in FY 81. Program improvements and changes, originating in-house and from contractors, have been assembled into a single segmented code. New theories have been documented in a report. Capabilities and uses of the program were documented in the form of a users guide and design manual reports. The code has been checked out and is available upon request, in source, UPDATE (CDC), or binary tape formats.

MODIFIED HYDROCODE FOR ROCKET EXHAUST ANALYSIS

A two-dimensional, time dependent, axisymmetric, inviscid hydrocode, SHELLTC, was modified to account for the presence of solid and liquid metallic oxide combustion product particles contained in a rocket exhaust. The presence of the metallic oxide is modelled by a two-phase coupled flow model. The coupling terms, a drag force term and a convective heat transfer term, appear in the finite difference equations for the particulate and gas phases. Computations are shown for various particle size groups using uncoupled and coupled models. Computer memory requirements place a restriction upon the maximum number of particle size groups that can be included in a simulation. Examples are given for the impingement of a restrained firing exhaust from a Mark 36 Sidewinder rocket motor upon a plate 1 ft from the nozzle exit.

AERODYNAMIC CODE FOR AIRBREATHING MISSILE CONFIGURATION

An attempt to develop a capability to compute aerodynamics on nonaxisymmetric airbreathing configurations is continuing. The approach has been to develop near and long term capabilities. Local solution methods are being adapted for near term capabilities for Mach numbers above 2.5. Approximate methods are being investigated for low and high supersonic Mach number ranges and for bodies at significant angles of attack.

JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY

J.C. Hagan, M.D. Griffin, and R.E. Lee

The continuing efforts in two projects related to ramjet flow field studies were described. One is the application of computer codes to study hypersonic inlet configurations. The other is the development and application on nonintrusive techniques to study combustion flow fields.

Shock-capturing finite difference methods are being applied to the development of practical codes for the inviscid analysis of hypersonic inlet designs. These codes are being used to select promising designs for model fabrication and testing. Specific areas which have been studied recently include the effect of cowl lip blunting on internal inviscid kinetic energy efficiency, and the effect of angle-of-attack variations on inlet performance parameters such as additive drag, air capture, and kinetic energy efficiency.

Laboratory-developed nonintrusive optical techniques for measuring flow properties and species distributions are being examined to determine their applicability for use in the ramjet engine testing environment. Recent efforts have been directed toward evaluating the full capability of the LDV technique for measuring velocity, particle size and particle number density using computer analysis and simulated cold flow testing in a Mach 3.5 supersonic jet.

GAS DYNAMIC RESEARCH AT THE BALLISTIC RESEARCH LABORATORY

E.M. Schmidt

The Ballistic Research Laboratory (BRL) is responsible for the conduct of investigations into the gas dynamics of or associated with Army weapons. This includes in-bore flow, muzzle blast, free flight aerodynamics, and terminal effects. Over the past year, the major areas of investigation were:

INTERIOR BALLISTICS

A significant effort is being expended in attempting to develop the capability to compute the two phase, viscous flow within a gun tube. This research is undertaken in order to resolve disagreement between predictions of one-dimensional models and experiment.

MUZZLE BLAST

The Army is experiencing difficulties in achieving acceptable levels of crew station blast overpressure during firings of high performance weapons. Techniques are being developed which will permit calculation of the three-dimensional blast field associated with a cannon.

PROJECTILE AERODYNAMICS

One of the BRL thrust in fluid dynamics involves the computation of projectiles aerodynamics over the full flight performance regime. This requires computation of subsonic, transonic, and supersonic gas dynamics. Particular emphasis is being given to determination of stability parameters including magnus force and moment and dynamic terms.

TERMINAL EFFECTS

The Army is highly concerned with the survival of equipment on the nuclear battlefield, The BRL is conducting both experimental and theoretical research to quantify the loadings upon equipment due to nuclear blast. A new area of research is centered on characterizing thermal-to-blast synergism.

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

C.H. Lewis

Recent work in predicting three-dimensional hypersonic viscous flows over ballistic and lifting reentry vehicles has been directed toward (1) predicting the flow field over the windward side of the space shuttle during reentry at angles-of-attack to 45 deg, (2) predicting the effects of angle-of-attack and yaw of axisymmetric and nonaxisymmetric bodies, and (3) predicting the effects of spin and/or mass transfer on blunt bodies at angle-of-attack.

During the past year, a new viscous shock-layer code (VSL81) has been developed and applied to the shuttle under perfect gas wind-tunnel conditions. Equilibrium gas and transitional and/or turbulent flows can be treated. Comparison with wind-tunnel data shows good agreement.

Since the last NAC meeting, a parabolic Naviar Stokes (PNS) code has been developed to treat angle-of-attack and yaw of nonaxisymmetric as well as axisymmetric bodies. Laminar, transitional, and/or turbulent flows of perfect gas or equilibrium air can be predicted. The accuracy of the predictions is currently being evaluated.

Also, since the last meeting, a PNS code was extended to treat the effects of spin and/or mass transfer for laminar, transitional, and/or turbulent flows. The strong effects of grid size on the predictions of magnus forces and moments is currently under study.

In the future, we plan to further evaluate the accuracy of the predictions using two different turbulence models, the effects of grid size on the predictions and range of capabilities (such as angle-of-attack and body geometries) of both PNS and VSL81.

NIELSEN ENGINEERING AND RESEARCH, INC.

J.N. Nielsen

EULER CODE STUDIES OF VORTICITY FLOWS IN MISSILE AERODYNAMICS

Under an Office of Naval Research contract, Euler equations have been used to solve for the supersonic flow over a wing-body combination including the effects of symmetric body vortices and vortex shedding from subsonic leading edges of horizontal fins. A series of runs have been made from α = 10 deg to 25 deg and free-stream Mach numbers from 3 to 5. Various details of the flow are shown.

For M_∞ = 3.0 and α = 10 deg the Euler results have been used to evaluate the accuracy of panel methods for determining the effects of body vortices on fin loads. Dr. Jack N. Nielsen is the principal investigator.

METHOD FOR DETERMINING THE AERODYNAMIC CHARACTERISTICS OF BALLISTIC PROJECTILES AT TRANSONIC SPEEDS

Under an Army Research Office, Durham contract, a theoretical method is being developed for determining the lift and pitching moment of ballistic projectiles throughout the transonic range. The theoretical method makes use of the transonic equivalence rule and uses inner and outer solutions. The method has been applied to both axisymmetric and nonaxisymmetric boattail shapes. As many as 110 separate calculations have been carried out in 30 minutes of computer time on the CDC 7600. Dr. Stephen S. Stahara is the principal investigator.

STUDIES OF STRUCTURE AND MODELING IN HOMOGENEOUS TURBULENCE

Under contract to the Office of Naval Research and with significant computational support by the NASA Ames Research Center, Nielsen Engineering and Research, Inc. (NEAR) has conducted studies involving turbulence modeling, and the basic structure of certain simple homogeneous turbulent flows. These studies have been used as the base "data" results from exact numerical simulations of the Navier-Stokes equations. The model studies have involved subgrid-scale models which represent the smallest-scale motions in large-eddy simulations, in which the largest scales in a turbulent flow are calculated explicitly. Evaluation of a model proposed by researchers at Stanford University has contributed to its development; it is now the most highly correlated with exact quantities of any model evaluated to date. Investigation has also begun into the basic structure of homogeneous shear flow. Computer graphics routines have been developed to allow "flow visualization" of the results of the exact Navier-Stokes calculations. It is hoped that the mechanisms for the production of turbulence energy and growth of the length scales in this flow may be deduced from the study of the resulting plots. Professor Joel H. Ferziger of Stanford is the principal investigator.

DEVELOPMENT OF A MODEL OF TURBULENCE NEAR A WALL FROM SOLUTIONS OF THE NAVIER-STOKES EQUATION

Under contract to the Office of Naval Research and with significant computational support by the NASA Ames Research Center, NEAR is using a new computational method to develop a model of viscous sublayer turbulence in incompressible flow. In this approach, the time-dependent Navier-Stokes equations are solved in the viscous sublayer subject to space- and time-dependent outer boundary conditions. These "edge" conditions are postulated based on experimental observations of organized eddy structure near a wall. This approach is the first one to attempt to incorporate directly conditions of the structure of the viscous sublayer into a turbulence model. Comparisons with experimental data of results computed in the sublayer using this technique are quite good for most turbulent quantities in spite of the use of very simple edge conditions, revealing the inherent potential of the method. Development of this approach is continuing under the guidance of Professor Dean R. Chapman of Stanford University.

VOUGHT CORPORATION
ADVANCED TECHNOLOGY CENTER

C.H. Haight and G.R. Hough

HIGH PERFORMANCE COMPACT SUBSONIC DIFFUSER

The objective of this program is to provide a proof-of-concept by experimental testing over a range of inlet initial conditions. The goal is to improve inlet performance and inlet-airframe integration, and to enable successful and accelerated use of viable RCS reduction concepts. Successful completion of the program described will provide a significant advancement of the design of high performance, short, subsonic diffusers suitable to apply to a large variety of supersonic inlet RCS reduction concepts.

EXTERNAL BURNING AND BODY CONTOURING

External burning with specially contoured afterbodies (EB/BC) was studied for base drag reduction or propulsion of projectiles and compared with base burning and external burning and base burning. Igniting the fuel-rich propellant in the thrusting direction provides the advantages of external burning with the added gain of the jet momentum. A simplified one-dimensional model was made and two-dimensional wind-tunnel tests were carried out at a freestream Mach number of 2. The strong relationship between contour length and shape, and propellant heat release rate, predicted from the analysis was verified. The best performance was obtained by matching chamber characteristics, freestream characteristics and afterbody design. Test results indicated that the effective base pressure increase was larger for EB/BC than for the other configurations and injection schemes, and also was larger than for an ideal nozzle at equivalent injection parameters.

AIRCRAFT SIGNATURE WITH LOW RCS WEAPON CARRIAGE

The objective of this program was to conduct preliminary tests and analyses to determine the potential of missile signature reduction and how these results interact with the overall carriage and integration with the aircraft. The tests were conducted on a full-scale STM vehicle, Vought's ALVRJ. The RCS measurements from this program provide a basis for developing design criteria and RCS reduction techniques which would be applicable to a tactical ramjet missile development program. The inlet test data showed improvements through the use of RAM in the inlet interior, screens, and shape changes to the inlet leading edges. The RCS contributions due to missiles features such as gaps were identified as being significant RCS contributors. The seeker antenna and radome was found to be the largest RCS contributor identified. The data will provide significant input to the specification of reduced RCS flow field criteria.

LOW OBSERVABLE MISSILES

Vought Corporation is under contract with the Air Force Wright Aeronautical Laboratory (AFWAL) to evaluate the impact of low-observable considerations on air-launched strategic missiles. The object is to determine the observable levels required, the degree to which those levels can be obtained through shaping, and the extent to which aerodynamic performance will be compromised by observable considerations. The study will start with the missile configuration resulting from the recently completed AFWAL Aerodynamic Configured Missile (ACM) study. The predictions will be based on an integrated analytical system which uses the same geometric configuration for aerodynamic, radar cross section, and infrared signature computations.

MULTIPLE LAUNCH ROCKET SYSTEM (MLRS)

Vought is prime contractor to the U.S. Army Missile Command for the MLRS. During the current Maturation Phase of the contract, 62 rockets have been successfully launched. Flight test results indicate the overall missile drag is near that expected. Monitoring of drag will continue to verify analytical and wind-tunnel test results. The best estimate of boost phase stability data currently shows negligible plume effects, although earlier full-scale wind-tunnel testing with a normal flow jet plume simulator had indicated strong plume effects. This area of aerodynamic definition will continue to be studied closely during the Maturation Phase.

VOUGHT HYPERVELOCITY MISSILE (HVM)

Vought is currently under contract to both the Armament Division, AFATL, and the Ballistic Missile Defense Advanced Technology Center to develop a family of small hypervelocity missiles that travel in excess of 4000 ft/sec and can penetrate rolled homogenous armor of thickness used by the majority of targets on a battlefield. In support of these contracts, two series of wind-tunnel tests have been carried out at Vought. The first series was conducted over a Mach number range of 0.8 to 4.8. The model was tested both spinning and nonspinning with angles of attack up to 20 deg. This test provided both basic aerodynamic characteristics and magnus effects. The second series tested the boundary layer interaction effects of the impulsive thruster control system. These tests indicated a small effect on the basic thruster impulse over the Mach number range 0.8 to 4.8. Additional aerodynamic and impulsive wind-tunnel testing will be conducted for the Eglin HVM contract in late 1981 and early 1982.

ASSAULT BREAKER

Vought is currently in the final phase of a 32 month contract to the Army Missile Command involving development of a submissile with submunition dispenser and a T-22 missile delivery system. The current phase involves a six flight demonstration test program using a 22-in. diameter vehicle to demonstrate technology capable of accurate, multiple, subweapon delivery exceeding a currently deployed Lance system range, payload, and delivery capabilities. Vought recently completed the first two flight test demonstrations at White Sands Proving Grounds. The tests involved supersonic flight of the T-22 missile to a precise aimpoint above the target area, controlled dispense of quantities of subweapons, and delivery of the subweapons within prescribed laydown patterns. A significant test result has been verification that subweapon separation is quite similar to preflight estimates predicted using analytical techniques. During both flight tests, subweapon laydown was achieved in the prescribed patterns and distribution. The actual impact patterns closely overlayed the predicted patterns.

EJECTOR TECHNOLOGY

Methodologies based on three-dimensional vortex-lattice and lifting-line theories and two-dimensional analog techniques were coupled with viscous flow predictions and impirically-based ejector augmentor design and performance procedures to establish the design of a high performance aero/propulsion ejector lifting surface. Superior lift and thrust performance, particularly at high angle of attack, were predicted for a configuration consisting of a constant-pressure mixing ejector with a lower surface inlet and upper trailing edge exhaust flow. This configuration was subsequently built and tested at Mach numbers up to $M_o = 0.3$, for a four ejector-bay configuration, and compared with a corresponding clean configuration tested at the same time. The test results indicate considerable improvements in L/D for the ejector wing when compared with the clean wing, and an increased angle of attack capability of $\Delta\alpha > 10$ deg without stall. The ejector agumentor, although designed to improve wing performance rather than provide thrust augmentation, provided a thrust augmentation ratio $\phi = 1.07$ at the $M_o = 0.3$ condition, as predicted in the design studies. Key elements of the work will be appropriate to aero/propulsive integration for cruise/maneuvering missile configurations and for ejector/mixing suppression of nozzle IR signatures.

TURBULENCE MODELING FOR PROPULSION INDUCED EFFECTS

The model is a three-dimensional extension of an approach used previously for prediction of inlet flow maximum distortion levels and two-dimensional channel flow characteristics. Analytically, in conjunction with centerline and wall boundary conditions, it forms the closure required for the governing cylindrical Reynolds and kinetic energy turbulent flow equations. Applicability of the model to shear flows is presently focused on a fully developed turbulent pipe flow. The solutions are expected to completely characterize the flow with a single distributive set of vortex (or eddy) properties. Comparisons with an extensive pipe flow database will be used to verify the predicted characterization. In addition, the solutions will provide the framework for coupling the analysis with experimental boundary (or initial) conditions to define scaling relations. The results will be applicable to three-dimensional turbulent flow boundary layers and flow mixing problems in general, and ultimately to missile base flows and aircraft propulsion induced effects where jet mixing and entrainment affect the flight/model scaling and simulation requirements. It also appears that the present three-dimensional turbulence model will be useful for estimating the effects of turbulence on plume infrared emission, and laser attenuation as affected by plume turbulence.

GRUMMAN AEROSPACE CORPORATION
RESEARCH DEPARTMENT

R.A. Oman

Gas dynamics projects in the Research Department at Grumman Aerospace Corporation include compact diffusers; supersonic and hypersonic flows over control surfaces, cavities, and base regions; a variety of computational fluid dynamics activities in external aerodynamics; and an extensive program in exhaust plume fluid mechanics. The exhaust plume work includes problems of vertical takeoff and landing (VTOL) vehicles in ground effect, and the effects of plumes on engine-airframe integration and optical signatures of aircraft and missiles.

Slot blowing has been used to prevent separation in axisymmetric subsonic diffusers with divergence angles as high as 80 deg. Improvements in the prediction of resonance frequencies for rectangular cavities in transonic and supersonic flow have resulted from the use of new shear layer measurements. Progress in computational fluid dynamics is reflected in the widely used GRUMFOIL code for transonic airfoil analysis, and significant (e.g., 5x) reduction in computational time for transonic three-dimensional problems through the use of alternating direction implicit schemes. Some recent success has also been achieved in the computation of supersonic three-dimensional flows involving complex shock interactions. Carefully formulated small-scale experiments have been shown to give accurate representation of in-ground-effect flow fields of full-scale VSTOL aircraft that employ fan jets. Substitute gases have been employed to represent the behavior of scramjet exhaust gases in wind-tunnel testing. Gas dynamics, chemistry, and radiation transport computer codes are being developed and applied to infrared, ultraviolet, and visible signatures of aircraft and missiles in a variety of programs, especially those coordinated through the JANNAF Tactical Missile Signatures Panel. These are being supported by shock tube experiments in photochemistry, propellant kinetics, high temperature aerosol radiation transport, and plume simulation.

MCDONNELL-DOUGLAS ASTRONAUTICS COMPANY - HUNTINGTON BEACH

J. Xerikos

DEVELOPMENT OF A ROUGH WALL OPTION FOR A THREE-DIMENSIONAL TURBULENT BOUNDARY LAYER CODE

Ground test results have indicated the possibility of significant surface roughness effects on vehicle shock layer properties at supersonic/hypersonic speeds, e.g., representative heatshield roughness levels appear to cause a reduction in control effectiveness relative to smooth wall values. To further investigate this potential problem, a three-dimensional turbulent boundary layer code has been modified to include a kinetic energy of turbulence equation in an attempt to model rough wall flow field behavior. A pilot version of the code, developed under the sponsorship of the Ballistic Missile Office, Norton AFB, Contract F04701-79-C-0073, is now operational. Calculated smooth and rough wall flow field properties, which include temperature and velocity profiles across the boundary layer, clearly delineate roughness effects. Reasonable agreement with available wind-tunnel data, such as, wall heat transfer axial distributions on slender blunt cones, has been obtained.

MODIFICATION AND DEVELOPMENT OF THE NSWC (PING/BING)/AERO COMPUTER CODE FOR SURFACE PRESSURE AND HEAT TRANSFER CALCULATIONS

In 1979, a computer code for aerodynamic load analysis for a missile was completed by MDAC under Contract N60921-78-C-0203 for NSWC-WOL. It analyzes a complete missile or its components (wing or body) and provides pressure distributions at given locations, as specified by the outputs of NSWC computer codes PING or BING on the missile surface. The aero code, as originally developed, was based on the linearized, small-disturbance equation of motion. It was later extended to include nonlinear effects in order to treat Mach numbers up to 6. The code has been further extended under Contract N60921-80-C-0259 to treat (a) aerodynamic heating at high supersonic speeds and (b) pressure distribution on a slightly blunted nose. The input modifications have been kept to a minimum. In the aerodynamic heating case, only a few of the appropriate material properties are required with the default values set for aluminum. The output includes temperature histories and corresponding heat fluxes at selected locations. Only two new inputs are necessary for the blunt nose case.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

J.R. Baron, M. Landahl, E. Murman and C. Haldeman

NONAXISYMMETRIC CONFIGURATION DEFINITION

Known supersonic disturbance fields may be combined advantageously to define families of configurations in terms of the relative strengths, axial and lateral locations, and number of the parent fields used. Such an inverse approach has been completed using conical shock surfaces numbering between two and four as examples. The resulting geometries are nonaxisymmetric, range between their axisymmetric and two-dimensional field limits according to the scale selected, and exhibit piecewise conical fields with attached shocks. Generally, multiple shock surfaces lead to transitions from n-gonal star-like sections to corresponding n-tuple sections far downstream.

RESEARCH IN TURBULENCE AND RELATED AREAS

Research has mainly been focused on turbulence structure, its relation to hydrodynamic stability, and on possibilities of control of turbulence, especially for the reduction of turbulent skin friction. Recent efforts have primarily been directed toward an understanding of the mechanism of coherent structures in boundary layer turbulence. Employing an inviscid model incorporating nonlinear interaction between small-scale and large-scale bodies, it has been found that an eddy of large horizontal scale (a "flat" eddy) may be created from local intermittent small-scale instability. Such an eddy is shown to evolve with time and downstream travel so as to produce thin layers of strong shear, which in turn may give rise to new regions of instability, thus generating new turbulence. The mechanism responsible for shear layer formation is primarily stretching of mean spanwise vorticity, with induced pressure gradients playing a minor role in this process.

SCRAMJET DUAL MODE COMPUTATIONS

A SCRAMJET operating below the design flight Mach number may not maintain supersonic flow through the combustor. This condition can produce standing shock waves and mixed subsonic and supersonic flows within the combustor. The rate of heat release as well as the area change in the combustor, together with the combustor wall viscous effects, all influence the flow. If present, any subsonic flow in the combustor must be reaccelerated to supersonic speeds in order to maintain engine thrust. One technique to accomplish this is to tailor the heat release so as to generate thermal choking. The general situation described above is sometimes referred to as dual mode operation.

A computational analysis has been undertaken to investigate the fluid dynamic aspects of dual mode operation and, in particular, how the flow is influenced by the heat release distribution. At present, a one-dimensional unsteady numerical model is under development. The equations are to be solved by means of a time dependent finite difference technique with consideration of both steady and unsteady flows.

MAGNETIC BALANCE SYSTEM MEASUREMENTS

Dynamic Stability

The recent addition of a dedicated MINC DEC 11-23 minicomputer to the magnetic balance system permits consideration of dynamic stability derivative measurements using electrical white noise excitation. This procedure both eliminates aerodynamic support interference and makes possible the testing of unusual and complex shapes. Preliminary data have been acquired for $C_{m_{\dot{\alpha}}} + C_{m_q}$ for a length-to-diameter ratio equal to five tangent ogive cylinders. At 300 ft/sec and a 0.5×10^6 Reynolds number (based on diameter) it appears that measurements are realistic with random noise excitation corresponding to 0.2 deg to 0.4 deg amplitudes. The resolution and sensitivity are quite good, but analog data filtering is needed to reduce the scatter that comes about due to a low signal-to-noise ratio at the computer input. Pitch damping is derived from the change in bandwidth of the Fourier transform of the natural resonance in pitch.

GAS DYNAMICS PANEL RECOMMENDATIONS TO NAC

The following recommendations were generated by the panel during the meeting.

1. RECOMMENDATION:

Continue to develop inviscid Euler flow codes with emphasis on the prediction of flow fields containing regions of subsonic flow. This effort should emphasize:

a. development of efficient hybrid methods for use in three-dimensional supersonic flow-fields containing subsonic regions, and

b. development of new computational methods aimed at achieving rapid convergence to the steady state for the three-dimensional subsonic flow fields.

BACKGROUND:

Potential flow and linearized flow assumptions have severe limitations concerning their application to missile aerodynamics at high angles of attack because of strong shocks and rotational flow. Additional problems are encountered in dealing with wing- or fin-body interactions even at moderate angles of attack. Inviscid or Euler codes are a promising method for handling these problems without going to the complexity of full Navier-Stokes equations. When the axial Mach number is supersonic, the Euler equations admit the very rapid and general marching method of solution. However, when the axial Mach number is subsonic (or is subsonic in a small region within the flow field) this method breaks down. Existing methods for subsonic flow require some form of iterative solution and are very inefficient, requiring as many as 600 iterations for acceptable convergence.

2. RECOMMENDATION:

Experimental programs should be undertaken to determine surface pressures on the body and lifting surfaces of circular and noncircular finned configurations typical of advanced tactical missiles for Mach numbers between 3 and 8. In addition, flow field surveys should be made to determine shock layer properties with emphasis on separated flow regions.

BACKGROUND:

In response to future tactical missile requirements, efforts are ongoing to predict the aerodynamics of tactical missile configurations (e.g., circular and noncircular bodies with wings and/or fins). Data are needed for preliminary design and to validate the predictive methods.

3. RECOMMENDATION:

Improve the existing gas dynamic models for predicting rocket and ramjet plume phenomena. Specific areas that drive the ability to predict optical signatures, weapon launch interference effects, and guidance interference effects are:

1. afterbody and base separation phenomena
2. exit plane definition
3. solid particle propagation in plumes and nozzles
4. ad hoc turbulent mixing models
5. Mach disk formation and location models

State-of-the-art code development and specific validation experiments are needed in all of the areas mentioned.

BACKGROUND:

A standardized plume flow field (SPF) code is currently emerging for use by vehicle design and detection system specialists. This code has specific gas dynamic limitations that are currently the primary source of errors in IR, visible, and UV signature predictions (i.e., attack warning range and time) and in optical guidance system interference. The most immediate needs are for the development of base effects models for incorporation with SPF, the selection of the most appropriate mixing models for use in particular plume situations, an improved Mach disk model, and the formulation and execution of validation experiments to confirm or to guide the way to improvement of the current SPF modeling. Any Navy contribution to this Triservice program should be coordinated through the JANNAF IR and UV Tactical Missile Signatures Panel.

4. RECOMMENDATION:

Develop flow field computer codes capable of describing three-dimensional steady and unsteady internal flows with boundary discontinuities such as those found in side dump ramjet combustors. Continue support of experimental studies to guide the analytical modeling and validate the models developed.

BACKGROUND:

The need for tactical missiles having high speed and long range dictates the use of high performance, volumetrically (and weight) efficient propulsion systems such as ramjet engines. Past ramjet engine developments have relied extensively upon experimental and empirical approaches which are generally expensive and usually do not provide a basic understanding of the flow processes within the combustor. Experimental new analytical tools, which provide insight into the flow mechanisms within ramjet combustors, are needed to reduce the cost of the development of future advanced ramjet propulsion systems. Three-dimensional internal flow models are needed which can described the flow in more volumetrically efficient side dump ramjet combustors or combustors having complex geometries not readily describable by two-dimensional internal flow field models.

5. RECOMMENDATION:

Continue to support analytical and experimental efforts to model and understand the complex interaction between ramjet inlets and combustors associated with low frequency combustion instabilities.

BACKGROUND:

The Navy has a need for long range, high speed tactical missiles for both air and surface launched application. Ramjet propulsion systems currently in exploratory development are the most likely means of providing the propulsion for these future missile systems. Previous exploratory development efforts have shown that small liquid fuel ramjets configured for air-launched applications are subject to low frequency (100-500 Hz) combustion instabilities which result in large amplitude pressure oscillations. These unsteady back pressures are known to couple with natural unstable motion of normal shocks in supercritical inlets, sometimes resulting in inlet nonstart. A systematic investigation of the phenomenon from both an exploratory development and basic research point of view is required.

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1981 REPORT TO THE
NAVY AEROBALLISTICS COMMIT
FROM THE
HEAT TRANSFER
PANEL

INTRODUCTION

The panel met at the David W. Taylor Naval Ship Research and Development Center on 6-7 October 1981. Members present reported on accomplishments in their respective activities during the past year and formulated technical recommendations for consideration by the NAC. These are reported here.

The attendees were:

Mr. D.W. Boekemeier	McDonnell-Douglas Astronautics Co.
Mr. R.K. Frazer	Johns Hopkins University Applied Physics Laboratory
Mr. F.R. Frederick	General Dynamics, Pomona
Mr. R.M. Hartley	David W. Taylor Naval Ship Research and Development Center
Mr. R.J. Joachim	Raytheon Co.
Dr. R. Kosson	Grumman Aerospace, Corp.
Dr. B. Laub	Acruex Aerotherm
Mr. R.K. Matthews	ARVIN/CALSPAN
Mr. J. Medford	Vought Corp.
Mr. P.F. Melia	United Technologies Corporation
Mr. T.V. Radovich	Martin Marietta Aerospace Orlando, Florida
Mr. F.A. Strobel	Naval Weapons Center
Mr. Andy Victor	Naval Weapons Center
Dr. T.F. Zien (Chairman)	Naval Surface Weapons Center

JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY

L.B. Weckesser, D.W. Conn, and R.K. Frazer

Heat transfer and rain erosion investigations have been conducted at the Applied Physics Laboratory during the past year to advance the "state of the art" in the design of high speed tactical missiles. Again this year substantial effort was directed at analyzing and testing sensor windows, with increased emphasis on radome performance during flight through rain. A brief summary of each project related to heat transfer and/or rain erosion is presented next. A bibliography following the panel recommendations provides a more complete reporting of these projects.

SENSOR WINDOW PROJECTS

RADOME MATERIALS FOR HYPERSONIC FLIGHT - T.K. Fryberger

An analytical screening investigation has been conducted to determine which radome materials might be usable on a hypersonic tactical missile. The screening consisted of evaluating a matrix of two radome configurations, three trajectories, and ten ceramic materials for four possible failure modes. The failure modes included thermal shock, melting, aerodynamic loading, and excessive boresight error change. The screening was accomplished with the Unified Radome Limitations computer code (URLIM).

Materials that were studied include: Pyroceram 9606; Pyroceram 9603; Rayceram III; slip cast fused silica (SCFS); AS-3DX, a quartz silica composite; hot pressed silicon nitride; reaction sintered silicon nitride; hot pressed aluminum nitride; sintered aluminum nitride; and Sialon 128. The radome wall thickness was set for a half-wave in the K - a band for all materials. The SCFS was also studied in a full-wave configuration. The missile's angle of attack was set to produce a lateral acceleration of thirty g's up to a maximum angle of attack of forty degrees.

Pyroceram 9606, Pyroceram 9603, and Rayceram III were the only materials limited by excessive temperatures. Due to the thin wall design, thermal stress was not a limit for any material. Excessive attachment loads limited Pyroceram 9606, Rayceram III, and AS-3DX. The least sensitive material for boresight error (BSE) sensitivity is AS-3DX with a BSE sensitivity of 0.187 while the most sensitive material is sintered aluminum nitride with a BSE sensitivity of 3.19. For this study, the maximum allowable BSE sensitivity was set at 1.00. The most promising materials for all four criteria are: reaction sintered silicon nitride, both full- and half-wave SCFS, and Sialon 128.

THERMAL AND RADIO FREQUENCY VALIDATION OF THE SM-2 BLOCK II RADOME - L.B. Weckesser

The SM-2 Block II radome is predicted to experience wall temperatures up to 1300°F where substantial change in its radio frequency (RF) performance, can be noted. A radome design was developed that could perform acceptably when heated to the Block II temperatures. This design consists of an SM-2 Block I radome of Pyroceram 9606 with its wall thickness reduced by 0.003 in. and tuned with quartz tape at 75 MHz above the missile operating frequencies. A test program was carried out at the Department of Energy's Solar Facility in Albuquerque, New Mexico to validate the RF performance of this new radome design at flight type temperatures.

A total of 57 heated radome tests were completed during the program and the results revealed that all objectives were successfully met. Sufficient tests were performed at radome nose area temperatures of 450°F, 800°F, and 1300°F to show that the off frequency tuning concept is satisfactory for the SM-2 Block II missile. In addition to tests of the new Block II radome, heated radome tests were conducted on a constant wall, unfortified radome to provide data for evaluating boresight error predictive methods. Data were gathered on this radome for temperatures up to 1500°F and it should prove valuable for use in an evaluation of prediction codes.

Heated radome tests were also conducted on an SM-2 Block I radome at the Block II temperatures. The resulting boresight error data confirmed previous analytical predictions that excessive boresight error slopes would be experienced at the high temperatures. These data showed conclusively that the SM-2 Block I radome is unacceptable for use on the Block II missile.

THERMAL AND RADIO FREQUENCY RADOME TESTS FOR HYPERSONIC FLIGHT - L.B. Weckesser

A follow-on to the above program was carried out at the solar facility during March and April of 1981. Tests were performed on four tuned and one constant wall untuned Pyroceram 9606 radomes and one untuned slip cast fused silica radome. Radome test temperatures extended from 800°F to 2200°F with accurate boresight error measurements being made on all tests. The general conclusions from this test program, which has not as yet been documented, are that the Pyroceram 9606 radome causes boresight error slopes in excess of 0.04 deg/deg when heated to temperatures of 1400°F and above. Also, the data showed the slip cast fused silica radome to be quite stable at temperatures up to 1900°F and above that temperature its RF performance starts deteriorating rapidly. This work will be documented by the end of 1981.

THERMAL SHOCK TESTS OF STANDARD MISSILE RADOMES - R.K. Frazer

The Block III variant of STANDARD Missile 2 (SM-2 Block III) is being designed with a significantly larger booster motor than presently used for SM-1 or SM-2 Block II. The new booster design takes advantage of additional volume available in the vertical launcher system presently being developed. Theoretical calculations of thermal stress in the SM-2 radome were performed for the Block III flight condition that showed peak stresses of about 18,400 psi. This condition for Pyroceram 9606 was judged to be close enough to the design limit of 22,500 psi so that a demonstration test was required. Calculations showed that solar heat flux histories could be generated sufficient to meet and exceed the expected Block III stress values.

Black painted SM-2 radomes, mounted to the support stand used for BSE testing, were used for the thermal shock tests. For one test a shutter was used to create a solar flux rise time of 1 sec. Thermal stresses were measured on the inside surface of the radomes by strain gages. For the test using the shutter the radome failed at a stress level of 21,500 psi. A more gradual solar exposure was applied in the second test by commanding the heliostats to the radome in a unique manner. Due to thermal limitation of the strain gages used, the experimental data are available only up to 10 sec for this test. An extrapolation of this data was performed by using measurements of the radome external surface temperature to calculate the thermal stress which peaked at about 19,000 psi. The radome survived this test through 37 sec of exposure at which time the solar beam was removed; about 14 sec later the radome fractured. During cool down the outer surface cools faster than the inner surface of the radome. (During the solar heating, the tensile stress is on the inner surface.) It was estimated that this cool-down stress level was about 10,000 psi. A surface flaw of sufficient size could have been present on the outer surface to allow the relatively low stress failure. During the heating portion of the test this flaw would have been in compression and, therefore, would not have been a cause of failure.

The data show that the CRTF solar furnace produced very nearly the same thermal stress levels as are expected for SM-2 Block III flight. Further, the radome survived this shock. Additionally, a full-scale SM-2 radome failed at 21,500 psi during thermal shock, largely verifying the use of a value of 22,500 for design purposes. An overall conclusion from these two tests is that the SM-2 Block II radome, if made of Pyroceram 9606, will not be performance limited due to thermal shock. A secondary result of this effort is that the CRTF solar furnace can provide an adjustable heat flux that simulated advanced surface-to-air missile flight.

RAIN EROSION OF SLIP CAST FUSED SILICA - L.B. Weckesser

Two separate programs are being carried out at JHU/APL related to rain erosion of SCFS. A research and development (R and D) program is being sponsored by NAVSEA 62R to develop a method for predicting erosion of SCFS and validate it with sled tests. Presently, an empirical equation has been developed (Stadter, Sep 1981) and it will require experimental data to determine the constants in this equation. A program plan (Letter et al., Aug 1981) has been prepared for testing two radomes at the Holloman track. These tests will be conducted in May 1982 and plans are to make boresight error measurements on these radomes before and after the sled tests. This will provide data showing the erosion effect on the radome RF performance. The ultimate goal of this R and D program is to develop, not only an erosion computer model, but also a code that can be coupled to it for predicting boresight errors resulting from the erosion.

Based on the data obtained from the heated radome tests at the solar facility, a SCFS radome looks attractive for use on the SM-2 Block III missile. The "Achilles' heel" of this material, however, is its low strength and its susceptibility to rain erosion. Therefore, a test program is planned (Weckesser, Aug 1981), but not yet funded, to evaluate the erosion of SCFS radomes of the SM-2 size and shape. Again a boresight error map of the radomes will be made before and after the rain tests to show the erosion effect. Plans are to conduct these tests in series with those discussed in the previous paragraph to minimize test set-up costs.

RAIN ENVIRONMENT CONSIDERATIONS - L.B. Weckesser

An investigation has been initiated at JHU/APL to define the rain environment to be used as a specification for the SM-2 Block II and Block III missiles. Numerous telephone contacts have been made and reports reviewed to find material that would assist in defining rain rate and rain extent as a function of altitude. Much more work is needed in this area and presently it is planned to have a rain specification prepared by January 1982. Also, using an empirical procedure for defining fracture of Pyroceram 9606 radomes flying through rain, limit velocities were determined as a function of rain rate and length of travel in rain. Details of this work were documented by Weckesser, Sep 1981.

INFRARED DOME FOR SM-2 BLOCK III MISSILE - W. Tropf

Infrared guidance is under consideration as a supplementary terminal mode for the STANDARD missile. A preliminary study has been conducted concentrating on three important issues: (1) the survival of an uncooled hemispherical infrared dome in the high temperature (high speed) environment, (2) the seeker detection capability against high speed, high altitude missile targets, and (3) the capability of an infrared seeker to adequately search the target uncertainty volume using AEGIS midcourse guidance data.

Results show that the infrared seeker dome can survive the thermal environment of anticipated trajectories. A seeker concept of operation is reported by Tropf (May 1981) that allows good detection capability against missile targets. Candidate seekers show adequate search capability and the capacity to rapidly accumulate detection probability.

THERMAL DESIGN PROJECTS

CARBON ABLATION IN A RAMJET COMBUSTOR ENVIRONMENT - R.W. Newman

The design of passively cooled, hypersonic tactical missiles pose many severe structural problems whose solutions are beyond the current state-of-the-art. To design such a combustor, the designer must accurately predict the erosion rate of candidate materials so that a realistic balance can be achieved between weight, performance, and cost. To make these predictions, basic experimental data must be taken to determine ablation rates as a function of surface temperature, pressure, gas flow rate, and gas composition. Tests are currently in progress to make these measurements on ATJ graphite.

A series of preliminary tests were conducted to evaluate a method of measuring ablation rates of graphite materials exposed to high-temperature oxidizing environments (Hoshall, Jan 1980). The test procedure proved feasible, and the apparatus is now being modified to improve its performance. Once the modified apparatus is checked out, a series of tests will be conducted to provide ablation data for evaluating a model for the Charring Materials Ablation (CMA) computer program. The CMA thermochemical model will be evaluated by comparing measured ablation rates with analytical values obtained from CMA runs. If there are significant differences, modifications of the thermochemical model will be required. See also Newman, Jun 1981.

HYTAM GAS GENERATOR THERMAL ANALYSIS - R.W. Newman

As part of the JHU/APL exploratory development program on propulsion, an integral-rocket dual combustion (subsonic or supersonic) ramjet (IRDCR) concept is being investigated for use in a hypersonic tactical missile (HYTAM). In the design of the engine it is required to minimize ablation in the gas generator to keep flow area change less than 10 percent, otherwise engine performance would be reduced significantly. Previous analyses (Newman, Aug 1981) indicate that a solid carbon-carbon material meets this requirement. However, due to structural attachment limitations, the solid carbon-carbon liner is not suitable for the HYTAM gas generator. The design has been modified to use a tantalum supporting structure external to a carbon-carbon liner. Thermal analyses (Newman, Sep 1981) indicate that the revised design is adequate with less than 4.0 percent area change (i.e., less than 0.046 inch ablation) for both the Mach 6 and 7 high altitude cruise trajectories.

A second area of concern is to keep the tantalum support temperatures low enough to withstand combustor burst perssures. Peak temperatures were calculated to be 2340°F and 3010°F for the Mach 6 and 7 cruise trajectories, respectively. These temperatures appear to be low enough for the tantalum structure to withstand the burst pressures, however, a structural analysis is required to verify this design.

STANDOFF JAMMER SUPPRESSION THERMAL PROTECTION REQUIREMENTS - R.W. Newman

The Standoff Jammer Suppression (SOJS) program has been examining a ramjet-powered missile to engage jammer and missile launching aircraft at long ranges from a defended battle group. As part of this examination, critical missile components, such as the guidance electronics, warhead, fuel tank, auxiliary equipment, combustor, and actuators, have been analyzed (in a classified report by Constantine) to determine thermal protection requirements for two different trajectories as a function of flight time. With the possible exception of the inboard electronics, the insulation thicknesses required to meet the design goal are within practical size and weight constraints. Due to the large internal heat generation in the inboard electronics, active cooling will be required if active guidance is used for over half the flight time.

Combustor liner requirements were analyzed for three missile configurations and the required DC-93-104 insulation thickness for each configuration was found as functions of range and maximum allowable case temperature. A conventional steel case is limited to a maximum temperature of 1100°F because its modulus of elasticity decreases sharply at this temperature. Consequently, for the lower speed-longer range case, a steel chamber wall required 0.62 in. of insulation while the same missile at higher speed and shorter range requires 0.55-in. insulation. Because these thicknesses greatly reduce booster propellant capacity, an alternative is to replace the steel case with 718 Inconel which can withstand 1750°F before its modulus is significantly reduced. Because Inconel and steel have nearly the same heat capacity per unit volume, the predicted steel temperatures are applicable to both materials. Inconel reduces the required insulation to less than 0.1 in. for both configurations, although a practical minimum of 0.25 in. has been assumed for all missiles.

ASAR COMBUSTOR INSULATION TESTS - R.W. Newman

A test program has been conducted at the Allegany Ballistics Laboratory to determine the propulsion characteristics of an integral-rocket ramjet for use in the ASAR missile.

In conjunction with these tests, the combustor liner of DC-93-104 was evaluated. Heat lamps were used to simulate external aerodynamic heating of a portion of the combustor case. On January 21 the rocket-ramjet was successfully tested for 29 sec. The test was originally planned for 45 sec, but ramjet fuel flow rate was inadvertently reduced to one-tenth its normal value when a pressure reference line ruptured at 29 sec. The combustor case was instrumented with nineteen thermocouples with an additional six thermocouples located on the headcap. The important thermal results are (Newman, Feb 1981):

1. During transition to ramjet propulsion a severe vibration removed all the 0.005 in. diameter thermocouples from the case. In addition, over half of the 0.015 in. thermocouples were torn from the case.

2. Prior to their removal, thermocouples located under the heat lamps showed case temperatures were as expected, indicating the quartz lamps were able to simulate the desired aerodynamic heating.

3. Thermocouples on the headcap inlet ports agree well with previous data and indicate no "flashback" of combustor gases into the duct.

4. Headcap temperatures were much greater than expected indicating higher than anticipated ablation of headcap DC-93-104 insulating material.

NONINTRUSIVE DIAGNOSTIC INSTRUMENTATION DEVELOPMENT - R. Lee

Laboratory-developed nonintrusive optical techniques for measuring flow properties and species distributions are being examined to determine their applicability for use in the ramjet engine testing environment. Selected techniques are tested and evaluated in the sonic exhaust jet of a small-scale simulated ramjet combustor which is operated at nominal combustor pressures up to 60 psia, inlet air temperatures from

1260°R to 1560°R and fuel equivalence ratios from 0.8 to 4.0 using JP-5 fuel. Successful techniques will be applied to full-scale ramjet engine testing.

Preliminary measurements in the small combustor showed that the laser doppler velocimeter (LDV) could be used to measure the size and velocity of combustion products; particle sizes from 3 to 30 μm and velocities from 600 to 1400 m/s. This year's work has concentrated on the detailed evaluation of this technique using computer codes of diffraction theory and mu scattering theory together with calibrations in a small Mach 3.5 air jet seeded with particles of known size and shape. In addition, an electronic signal processor was designed and incorporated to permit a more rapid data interpretation. See Lee et al., Oct 1980 and Billig et al., May 1981.

AEROSPACE NUCLEAR SAFETY PROGRAM

RADIOISOTOPE HEAT SOURCE AND HEATER UNIT PROGRAMS - D.W. Conn

Lightweight Radioisotope Heater Unit (LWRHU) Program

The APL has completed the reentry thermal design for the LWRHU in compliance with tighter system operational and safety requirements than those imposed upon previous heater unit designs. The LWRHUs will be used aboard the Galileo and International Solar Polar spacecraft to provide thermal conditioning of temperature sensitive hardware.

The LWRHU design consists of a 1-in. diameter, 1.25-in. long right cylinder having an external shell (i.e., heat shield) of three-dimensional carbon-carbon. The right cylinder envelope was set by packaging constraints and complicated design requirements were set by requiring accommodation for either end-on or side-on reentries due to the aerodynamics associated with low fineness ratio cylinders. The design development was supported by numerous detailed reentry analyses for various assumed accident scenarios. These analyses included the use of a two-dimensional 760 node model for the end-on mode and a three-dimensional 500 node model for the side-on mode. See Monthly Technical Progress Reports, Jan-Jun 1981 and Conn, Jan 1981.

General Purpose Heat Source (GPHS) Program

The GPHS is the latest generation radioisotope heat source that will be used in the thermoelectric power systems for the Galileo and International Solar Polar spacecraft. This design employs a concept for standardization wherein modules can be stacked within a thermoelectric converter to meet mission specific power requirements. Each GPHS module contains a 250 thermal watt inventory consisting of four, discrete plutonia fuel assemblies.

The GPHS external shell is also of three-dimensional carbon-carbon material with overall dimensions of 2 × 2 × 4 in. The parallel piped aerodynamic configuration was dictated in large part for operational packaging efficiency, but also includes safety requirements by providing a low ballistic coefficient reentry to reduce aerodynamic heating and impact energy environments.

The JHU/APL is currently conducting an independent reentry safety assessment for this design for accident scenarios providing design environments relative to the ablation, thermostructural, and thermal response and impact failure modes. A three-dimensional 800 node thermal model will be used to examine the hypersonic or supersonic random tumbling portion of reentry and may be expanded to a [illegible]00 node network during stabilized subsonic reentry to evaluate impact performance. See Monthly Technical Progress Reports, Jan-Jun 1981 and Perini, Feb 1981.

ADVANCED SYSTEMS AND TECHNIQUES - D.W. Conn

Verification of Finite Differencing Codes

An effort is underway to evaluate the computational accuracy of various heat transfer calculation procedures contained in the JHU/APL's Standard Heat Transfer computer code library. The core of exact solutions to provide the basis for this evaluation will be the series "Temperature in Structures" (NAVORD REPORT 5558) published by NOTS in the late 1950's. This study has included the evaluation of interface heat transfer calculations with explicit finite differencing by using Thorne's single space, two-layer plate exact solution. The implicit approximate factorization technique is currently being evaluated through comparison with Barrett's two space, single layer exact solutions. This is a low level effort that will be supported as time permits from other project activities. See Monthly Technical Progress Reports, Jan-Jun 1981; Thorne, Mar 1958; and Barrett, May 1958.

Calculation Procedure for Interface Gaseous Conduction

A computational procedure is being developed to refine open interface heat transfer calculations involving the gaseous conduction mode. Prior calculations assumed an interface fill gas to reside in the continuum state. This procedure will determine the pressure histories at the various internal interfaces from a reference vacuumed state at the time of initial reentry. Pressure histories will be determined via (a) the net mass transfer of air diffusing across the porous carbon-carbon aeroshell as a function of local external pressure distribution, in addition to (b) accounting for helium release from the plutonia fuel (as a function of fuel temperature) and resulting helium discharge from the vented containment shell. The combined pressure and temperature computations at the interfaces then permit determination of interface gaseous conduction over the free-molecular to continuum density spectrum. This procedure will be incorporated into the forthcoming reentry analyses for the LWRHU and GPHS. See Monthly Technical Progress Reports, Jan-Jun 1981; Perini, Mar 1981; and Perini, Jun 1981.

NAVAL SURFACE WEAPONS CENTER

J.F. Yagla and T.F. Zien

INTERNAL BALLISTICS OF GUIDED MISSILE LAUNCHING SYSTEMS

The analysis of the internal ballistics of missile launching systems is a challenging engineering problem requiring the application of a variety of engineering techniques and the development of complicated mathematical models. The calculations first require a detailed knowledge of the rocket exhaust product as the material leaves the nozzle of the rocket motor. Very sophisticated numerical techniques and large computers are required to analyze the dynamics of the gas motion through the exhaust management system. Two-dimensional, nonsteady, compressible flow analyses have been useful in developing an understanding of the flow processes, and have provided velocity fields for the heat transfer analysis. Quasi one-dimensional nonsteady flow techniques have been useful for calculating wave motion through the system and for determining mechanical design criteria. The thermal response and performance of the protective materials used in the system have been analyzed by adapting turbulent convection heat transfer models for use with the quasi one-dimensional gas dynamics analysis. The thermal response of the ablative material, which consists of charring pyrolytic decomposition and evolution of gaseous hydrocarbons and carbon monixide has been analysed, and the results used in the gas dynamics analysis to study the chemical composition of the material passing through the system. The plume code LAPP, with chemical reactions and turbulent mixing, was used to obtain boundary data and chemical composition data for use in analyzing the flow of exhaust and entrained air through the system, and in determining the final chemical composition of the exhaust material trapped in the vehicle launch system. The final mixture for a specific launch sequence was analyzed for combustibility and found to be safe from the standpoint of accidental combustion or detonation.

HEAT TRANSFER DATA REDUCTION TECHNIQUES

One important problem in wind-tunnel experimentation is the determination of heat transfer measurements on the surface of the test model. Unfortunately, obtaining direct measurements of heat fluxes on the surface of the model is prohibitively expensive. One alternative possibility is to measure temperatures inside the test model (which is hollow) and use this data to determine heat fluxes. The resulting mathematical problem is ill-posed and requires special methods to avoid instabilities. A prototype data reduction program was developed based on adaptation of a method of Alifanov for a similar problem. The program ignores transverse effects and assumes constant material properties.

The method uses the Green function for the heat equation to recast the problem as an integral equation. The integral equation is of the first kind and although it is uniquely solvable, standard solution techniques are unstable. Instead, Tikhonov regularization methods are used to compute stable approximate solutions.

Numerical experiments for several typical cases have yielded excellent results even in cases with relatively high measurement errors.

TRANSITION PREDICTION BASED ON A NEW TURBULENCE MODEL

The objective of this investigation is to develop a single transport model from the Navier-Stokes equations for accurate predictions of skin friction, heat transfer, and fluctuating kinetic energy distributions in transitional and turbulent flow regimes. Specific applications are to provide the needed technology base for better Navy tactical and strategic weapon designs.

The beginning of the transition of a laminar boundary layer on a flat plate was reasonably predicted based on our turbulence model. The computation was carried out by considering a small disturbance at a frequency of f = 30 starting from the neutral stability curve. When the disturbance was amplified by about 200-fold according to the linear stability theory, the amplified disturbance distribution was used as the initial condition for our turbulence model equations to continue downstream. The beginning of the transition, defined as the location of minimum skin friction coefficient, was found to be at $Rex \approx 3.0 \times 10^6$ which is in good agreement with the measured value of $Rex = 2.8 \times 10^6$ as reported by Schubauer and Skramstad. See Chien, Apr 1981 and AIAA Journal.

CALCULATION OF AERODYNAMIC HEATING RATE FOR BLUNT NOSETIP

Axisymmetric hypersonic viscous flow over a blunt nose is simulated by solving the unsteady Navier-Stokes equations with a thin-layer approximation using an implicit factored scheme. The flow is assumed to be inviscid at the shock which is tracked. For simplicity, the shock and body boundary conditions are imposed explicitly. The steady solution is obtained asymptotically in time. The laminar heat transfer rate has been calculated for a hemisphere-cone at Mach number 5.92 with a Courant number of 75 and the result, in terms of Stanton number, compares well with experimental data and boundary layer calculation. A similar calculation has been made for turbulent flow under the same flow condition with an algebraic turbulence model. However, no comparison of the results can be made because of a lack of measured data.

An extension of a similar calculation for indented nosetip configurations and an investigation of other turbulence models are in progress. See Hsieh, future NSWC Technical Report.

HYPERSONIC HEAT TRANSFER ON ELLIPTIC CROSS-SECTION NOSETIPS

An extensive database on a 2:1 elliptical nosetip shape (5.0 in. major axis), to be used for verification of the AVCO MTSCT three-dimensional transition code, was generated in the NSWC Hypersonic Tunnel at Mach 5. Four nosetip models, in which the surface roughness varied from a smooth wall to a roughness value of 10 mils, were tested. The roughness values were determined from a photomicrographic technique and were based on a 30 percent probability of exceedence of the roughness heights. For the 10-mil model, copper particles were brazed to the model surface in a vacuum furnace.

Three nosetips were instrumented with 112 back-faced chromelalumel thermocouples. The 10-mil roughness model instrumentation consisted of 67 thermocouples and 31 Statham pressure transducers. The test matrix consisted of sixty runs where the variables included angle-of-attack, tunnel Reynolds number, and wall enthalpy ratio. Heat transfer data included tabulated and plotted values of the aerodynamic heating rate ($\dot{Q}$), heat transfer coefficient (H), and Stanton number (St) for each thermocouple. See Jobe, Jun 1981.

HEAT TRANSFER MEASUREMENTS ON A BLUNT 7 DEGREE CONE WITH BLOWING

Reentry body (RB) flight data have shown that, after passage through light, cirrus type cloud layers on some flights, small transverse velocity components have occurred which have had a significant effect on impact dispersion. An investigation of this "transient trim" phenomenon is being conducted as part of the Improved Accuracy Program (IAP) directed by the Strategic System Project Office (SP-272). One hypothesis for explaining the transient trim phenomenon is as follows: During passage through clouds small particles impact the ablating heat shield material and cause local cracking and flaking away of portions of the outer char layer. Alternately, or in conjunction with particle impacts, aerodynamic shear forces may cause flaking on flights where dynamic pressures during reentry are particularly high. This flaking leads to sudden exposure of the underlying virgin material to severe aerodynamic heating and as a result, very high outgassing rates may occur in localized areas. Local outgassing rates may be high enough to cause boundary layer separation which could, in turn, cause induced pressures large enough to have a significant effect on aerodynamic forces and moments.

This hypothesis was developed at Lockheed Missiles and Space Company (LMSC) as a result of theoretical studies of viscous effects in typical RB flow fields by means of numerical solutions of the Parabolized Navier-Stokes equations. An experimental investigation of the heat shield outgassing hypothesis was included in the IAP program for FY-81. This investigation was aimed at providing an experimental database to be used to evaluate the effect of high local outgassing rates on RB aerodynamics and to validate the theoretical flow field calculations performed at LMSC. The experimental program included tests run at Mach 8 in Wind Tunnel B at Arnold Engineering Development Center (AEDC) and tests run at Mach 14 in the Naval Surface Weapons Center (NSWC) Hypervelocity Tunnel. The wind-tunnel models used in both test programs were spherically blunted 7-deg half angle cones, and RB heat shield outgassing effects were simulated by blowing air (AEDC) or nitrogen (NWSC) through a porous section located just aft of the nosetip. The scope of the two wind-tunnel test programs was briefly as follows:

Both test programs included surface pressure, heat transfer and boundary layer/flow field survey measurement. The Mach 8 test program also included force and moment measurements.

The Mach 8 heat transfer and pressure tests included parametric variation on Reynolds number and blowing rate, and several tests were run with an indented nosetip shape in addition to those with the basic hemispherical nosetip. The Mach 8 force and moment test included parametric variation of the geometry (length and fraction of model circumference) of the porous section as well as blowing rate and Reynolds number.

One porous section geometry was investigated in the Mach 14 tests. Most of the Mach 14 tests were run at a single nominal blowing rate. Two runs with no blowing and one run with a higher than nominal blowing rate were also included, however. All Mach 14 tests were run at the same Reynolds number.

In both programs tests were run at zero angle of attack and at 3 deg angle of attack with windward and leeward blowing.

Pitot pressure surveys were made at three axial stations in both programs, and total temperature surveys were also included in the Mach 8 test program. See Ragsdale et al., Jun 1981.

NAVAL WEAPONS CENTER

F. A. Strobel

ROCKET MOTOR COOKOFF IN JP FUEL FIRES

Thermal analysis of rocket motors in fuel fires is performed at NWC in support of efforts to (1) make current operational rocket motors safe in fuel fires with a minimum number of modifications, (2) determine if new motor designs are potentially unsafe in fuel fires, and (3) evolve new design concepts to make rocket motors safe in fuel fires.

ENVIRONMENT

An overview document outlining the initial effort on the program Aeroheating of Advanced Configurations is in the process of publication as NWC TP 6292 "Overview of the Aerothermal Environment of Air-Launched Missiles." The additional planned effort on this program has been cancelled.

A representative of the NWC Thermal/Structures Branch has been participating in the revision of MIL-STD-210B, Climatic Extremes for Military Equipment. The main incentive for the revision is to make its correct use more obvious to the practicing engineer. The existing standard has been misused in that the environmental data have been applied directly to weapon systems without consideration for the use of the system or of the induced effects of the environment on the system. The current contents of MIL-STD-210B are extremes of the natural climatic environment. A proposed solution to this misuse has been to include induced data and cumulative probability measured storage data in the revision. We are opposed to the use of induced or response data in a military standard because these numbers are peculiar to the system under consideration and cannot be generalized. Another proposal has been to include yearly cumulative probability evaluations of the natural environment. We are opposed to this approach also, as a yearly presentation tends to damp out the seasonal cyclic temperature changes that are important to determining design requirements. We believe MIL-STD-210 should contain the natural environment only and that the environment should be presented so that realistic extreme conditions may be selected. Descriptive material should impress upon the user that he must select the environment for proper application to his particular system.

The following recommended temperature ranges have been widely promulgated for use in design:

Truck and Rail Transportation	-10°F to +115°F
Aircraft Carrier and Ship	+40°F to +90°F
Field Storage	-10°F to +130°F
Igloo and Covered Storage	-10°F to +120°F

We are opposed to these recommended temperature ranges because they are based on extensive but uncorrelated and unverified data taken in widely distributed but limited geographical areas. We feel also that such temperature ranges are a strong function of the particular weapon system design and usage and cannot be generalized. We agree past design temperatures have often been too extreme but the problem is not solved by using temperature ranges that are unrealistically moderate.

HARM MOTOR TESTS

In conducting tests on various missile components, it is often necessary to soak the component at a particular temperature prior to testing. Sometimes the soaking does not start at room temperature due to failure of the heating or cooling mechanism. Thus, it is desirable to know the time to reach a particular soak temperature starting from any initial soak temperature. An analysis to predict these times was performed for the Harm motor tests and is now used in planning pre-test soak times.

STORAGE TEMPERATURES

There has been a continuing need for prediction of the temperatures experienced by missiles in open storage. Continuing analyses and tests have been performed on this problem for varying geographic locations and missile surface colors. Analyses in the past year have been concerned with Sidewinder, Harpoon, and Harm missiles. A persistent question in these analyses has been the value of solar absorptivity of the weapon surface. This parameter has a strong influence on the temperature response of the missile exposed to direct sunlight. A particular problem has been the solar absorptivity of various colors of gray, the color currently being used on many weapon surfaces. The temperature achieved by a gray painted missile in hot open desert storage (solar absorptivity assumed about 0.6 and 0.8) can be marginal for subsequent successful operation of some components such as motor, warhead, and guidance sections. Thus, the precise value of solar absorptivity used in a particular analysis takes on even greater importance. For this reason tests were performed on two samples each of gray paint as used on the F-18 and white paint. Results were as follows for solar absorptivity: 0.25 and 0.266 for the white paint, 0.514 and 0.519 for the gray paint. These values for solar absorbtivity would not generally result in destructively high temperature response for hot desert storage conditions.

THERMAL ANALYSIS ON THE CASE RESPONSE OF THE MK30 SUSTAINER MOTOR

Thermal responses of the case wall and surface of the MK30 sustainer motor exposed to both aerodynamic heating and heat from the burning propellant grain were predicted using the general thermal analyzer, SINDA for aeroheating calculations and a charring material thermal response and ablation computer code, CMA, to predict the thermal response due to internal motor burn. This work was done at the request of the Naval Ordnance Station at Indianhead, Maryland. Analysis was performed at three locations on the missile. Location (1) with no outer insulation was exposed to aeroheating only, location (2) with an outer cork insulation was exposed to both aeroheating and half of motor burn, and location (3) with an outer cork insulation was exposed to both aeroheating and all of motor burn. The results show that the maximum case temperature was 593°F at location (1). An impinging shock wave will increase the surface temperature of location (1) up to a maximum temperature difference of 230°F and the surface temperature of location (3) up to a maximum temperature difference of 300°F.

ADVANCED COMMON INTERCEPT MISSILE DEMONSTRATION (ACIMD)

Preliminary thermal analyses of the radome, seeker electronics, and rocket/ramjet motor for the Advanced Common Intercept Missile Demonstration (ACIMD) vehicle were completed. The high-flight speed and long-flight times to be encountered on ACIMD pose several severe thermal problems. Several methods of maintaining acceptable temperature levels within the seeker electronics were analyzed and are currently being evaluated.

A preliminary worst case aerothermal heating analysis has been performed for the ACIMD radome. One-dimensional analyses were performed at three locations on the radome: one, four, and twelve inches aft of the tip. Temperature response was determined for a variety of radome designs including ceramics, ablators, and ceramic foams. Heating rates represent those experienced during a 150 sec free flight at high altitude. Currently, Duroid 5870, a glass fiber reinforced teflon, is the leading candidate because of the thermal protection provided to the seeker section and because predictions show no ablation to occur.

A thermochemical ablation analysis was performed for the proposed ACIMD booster nozzle. One-dimensional analyses using the Charring Materials Ablation program (CMA) were performed at various locations in the nozzle. Because the boost time is short, less than 4.0 sec, back wall steel temperatures remain relatively cool. Problems were foreseen in the igniter ring area and additional silica phenolic insulation was recommended. Predictions for the carbon phenolic throat region show ablation depths to be great enough to cause significant performance loss.

A thermochemical ablation analysis was also performed for the ramjet combustion chamber. The analysis was performed to see if the DC-93104 insulator would provide adequate thermal protection to the motor case during the most severe ramjet operation. Results show case temperatures to remain in the material operating range throughout the entire flight. Although predictions show the DC-93104 to char through the entire thickness, chamber conditions were not severe enough to cause ablation.

Preliminary designs of the ramjet nozzle allowed exposure to the solid propellant boost. It was felt that this exposure, although in only a very small region, might allow unacceptably high ablation of the ramjet nozzle and cause severe performance losses. Because calculations of heat and mass transfer coefficients in the region of interest were not possible, analyses were performed for a range of values. Results of the analyses show that, for even very small transfer coefficients, significant ablation would occur.

HIGH TEMPERATURE PLASTIC RADOMES

Efforts are continuing in the evaluation and characterization of ablative radome materials as well as in the analysis and design of full-scale ablative radomes. These radomes use noncharring, reinforced teflon materials as an external coating or in a monolithic wall construction. Advantages over ceramic radomes include resistance to handling damage, thermal shock failure, and catastophic rain erosion damage.

Thermal or ablative characterizations of two ablative radome materials AVCO 8029 and Duroid 5870 have been completed by Aerotherm/Acurex. The ablation models derived for the two materials are compatible with Aerotherm's CMA program. In addition, Aerotherm has completed a rain erosion test study which has developed a methodology, using the ABRES Shape Change Code (ASCC), to extrapolate ground test data to flight conditions. A series of tests are recommended which would resolve modeling uncertainties to make credible extrapolations possible.

Two eight-inch diameter base secant ogive ablative radomes (AVCO 8029) have been fabricated by AVCO Corporation. These radomes as well as two Duroid 5870 radomes are scheduled for thermostructural testing in the NWC T-Range facility. Test conditions will simulate the aerodynamic heating experienced by a medium-to-long range air-to-air intercept missile. Pre- and Post-electrical tests will be conducted to determine the effect of surface recession on bore sight error slopes.

THERMOSTRUCTURAL EVALUATION OF SPINEL IR DOMES

Two Sidewinder-size hot pressed spinel domes manufactured by Coors Porcelain Co. were tested to failure in the NWC T-Range hot gas facility. These domes had survived heating conditions which had caused failure in thirty previously tested magnesium flouride domes. Failure in the spinel domes was caused by increasing the heating conditions. Calculated failure stress for the dome was from 28,900 psi to 41,800 psi, depending upon the property data used in the analysis. The magnesium flouride domes had failure stresses ranging from 4,500 psi to 10,500 psi. Future plans include T-Range testing of six sapphire domes manufactured by Raytheon.

AFTERBURNER PLUME SIMULATOR

The Afterburner Plume Simulator (APS) combustion system was flight tested on the F-86 aircraft. The purpose of the APS system is to produce an infrared radiation source similar in shape and intensity to that produced by modern fighter aircraft with their afterburners in operation. Test results indicate successful operation at low flight speeds; however, flameout was experienced at high subsonic Mach numbers. The system has been redesigned in an attempt to increase flame stabilization at the higher velocities.

PHOENIX SHROUD AERODYNAMIC HEATING SIMULATION

Simulated aerodynamic heating tests on the Phoenix warhead shroud assembly were performed at the NWC T-Range hot gas facility. The test hardware consisted of an air nozzle, nose cone, steel calibration shroud, and an apparatus to structurally load the test item during aeroheating to simulate flight loads. The temperature response of the steel calibration shroud was determined for a worst case Phoenix trajectory using a one-dimensional thermal analysis. The facility air flow rate and total temperature were varied to produce a temperature time response in the calibration shroud nearly the same as that which it would experience in actual flight. The first two shroud designs tested failed in the simulated flight environment. The third design, which was protected by an ablative coating of Tefzel material, was qualified and will be used in the production of the 54C Phoenix missile.

JET VANE THERMAL STRESS ANALYSIS

A thermal stress analysis was performed on the jet vanes used in the strap-on thrust vector control system in the Vertical Launch program. Three-dimensional temperature distributions within the copper-infiltrated, tungsten vanes were determined as a function of vane angle of attack and rocket motor chamber pressure and temperature histories. Predicted thermal stresses for two successful motor firings were within the capabilities of the copper-tungsten material.

EFFECT OF ANGLE OF ATTACK ON HEAT TRANSFER COEFFICIENT

As part of the thermal analysis effort on a current Naval Weapons Center weapons program, it was necessary to determine exterior surface insulation requirements in order to protect an antenna system. The required thickness was determined analytically by conventional methods and some experimental verification was conducted. During the course of the tests at the NWC T-Range hot gas facility, the question was raised as to the effect on heating and consequent thermal protection requirements due to angle of attack of the missile during free flight. It was determined from previously conducted trajectory analyses that the angle of attack could go as high as 10 or 11 deg. The thermal analysis had assumed zero angle of attack.

MCDONNELL-DOUGLAS CORPORATION - ST. LOUIS

D.W. Boekemeier

IN-SITU CALIBRATION OF FLIGHT HEAT TRANSFER INSTRUMENTATION

An approach for economically minimizing errors in surface heating rates obtained from subsurface, transient, temperature measurements has been developed. The method is used to determine the values of finite difference thermal model parameters which result in a least squares error solution. A known calibration heat flux is imposed on an instrumented surface and the measured temperature history is used in an inverse solution to calculate a heating rate. Systematic variation of independent model parameters until the calculated and calibration pulses agree within a prescribed tolerance results in a set of "calibrated" input parameters to the thermal model.

UNCERTAINTIES IN PREDICTING MISSILE STRUCTURAL TEMPERATURE

A study was completed to determine the uncertainty in predicting temperatures for missile structural components. Two-dimensional thermal models of an ablative radome and a structural joint were evaluated using the Ablative Analysis Program (335-T) and the General Heat Transfer (HEATRAN) programs. The analysis was completed for four typical trajectories to assess the effect of Mach number (Mach 3,4,5, and 6). The temperature uncertainties were determined by perturbing each uncertainty parameter (e.g., recovery temperature, heat transfer coefficient, material properties, etc.) individually while holding all other parameters at their nominal values. The uncertainty band of each parameter was then combined with the corresponding temperature sensitivity to produce the temperature uncertainty. The series of individual temperature uncertainties were combined by the Root-Sum-Square (RSS) method to yield the overall uncertainty factor. The results of this study have provided a systematic evaluation of all uncertainties and it has provided a ranking of the relative merit of each uncertainty source.

HEAT PIPE THERMAL CONTROL OF AVIONIC CIRCUIT BOARDS

Small heat pipes, with cross-sectional dimensions of 0.040 in. × 0.160 in. and with variable length, have been developed and integrated into individual electronic circuit boards and modules. The use of these heat pipes results in small temperature differences between electronic components and coolants. Analyses indicate that resulting lower component operating temperatures, and reduced coolant demand provide significant life-cycle-cost benefits for aircraft. Critical requirements, which are delaying implementation of heat pipes in production electronic systems, are: (1) demonstration of their application to an entire avionic system and the resulting benefits, and (2) manufacturing technology to establish a heat pipe production source.

PREDICTION OF PYROLYTIC GRAPHITE RECESSION IN RAMJET COMBUSTORS

A thin coating of pyrolytic graphite can protect the structure of advanced ramjet combustors from oxidation by the hot combustion gases. However, the pryolytic graphite also undergoes some oxidation, and recession rates must be known to predict the required coating thickness. Excess thickness increases the cost of the coating and degrades vehicle performance. Graphite oxidation was found to be primarily due to oxygen, and reactions involving gas phase molecules other than oxygen can be neglected. At gas temperatures above 3800°R oxygen begins to dissociate, and graphite oxidation due to atomic oxygen must be considered. At high temperatures atomic oxygen reacts with pyrolytic graphite 50 to 80 times as fast as molecular oxygen. For molecular oxygen, the Nagel and Strickland-Constable reaction rate model can be used to predict coating oxidation. In this model, the rate of reaction is a function of molecular oxygen partial pressure and coating surface temperature. To predict oxidation by atomic oxygen, a model proposed by Rosner and Allendorf is used. The atomic oxygen reaction rate is a function of atomic oxygen pressure, surface temperature, and reaction probability. For a dump stabilized combustor with gas temperatures near stoichiometric conditions (4400°R) in the recirculation zone, the pyrolytic graphite recession predicted for atomic oxygen was of the same magnitude as that expected from molecular oxygen.

POMONA DIVISION OF GENERAL DYNAMICS

F.R. Frederick

STEEL RADOME THERMAL DATA CORRELATION SM-2 BLOCK II ER CTV-2

The steel calibration radome, used for the SM-2 Block II ER radome qualification sled tests, was flown on the CTV-2 flight test. Instrumentation mounted in the radome wall measured temperature, pressure, and total heat flux. The data were collected for the purpose of determining the accuracy of present analytic methods and for gaining insight into the variation of transition Reynolds number with affects such as pressure gradient, wall temperature, and Mach number.

To date, the radome has been thermally analyzed, using a typical thermal model with two separate computer programs and the resulting temperature predictions compared with measured flight temperatures. Predictions were found to be generally between 10 and 15 percent higher than measured temperatures.

CORNING GLASS WORKS THERMAL SHOCK SALT BATH FACILITY PARAMETRIC EVALUATION

A series of five Standard Missile Radome thermal shock tests was recently run to determine the capability, in terms of stress level, of the Corning Glass Works Thermal Shock Salt Bath Facility. At present the facility is used for acceptance testing all Standard Missile radomes at 100 percent of the theoretical worst case flight stress level experienced by the SM-2 Block I ER configuration. However, because newer configurations of the Standard Missile have more severe thermal environments, it has become necessary to do acceptance tests at higher levels and, therefore, necessary to determine the capability of the salt bath facility.

Surprisingly, it was found that bath conditions used for the present acceptance test level (12,500 psi) are actually producing a stress level of 18,300 psi. In addition, while alternately varying the bath temperature and propeller speed, it was found that increasing the temperature increased the stress level, but increasing the propeller speed actually caused the stress level to decrease. Increasing the propeller speed also caused the stress at each station to become more nonaxisymmetric and the longitudinal stress gradient to decrease. Further analysis is required to determine the phenomenon behind the unexpected behavior with a change in the propeller speed.

PHASE CHANGE IN AN INFINITE SLAB SUBJECT TO TRANSIENT HEAT FLUX

An approximate analytical technique amenable to transient solidification and/or melting problems was developed. The problem considered was a slab of some homogeneous material, initially at a uniform temperature well above its fusion temperature, perfectly insulated on one face, and subjected to a uniform rate of heat removal from its other face. The questions addressed include: How does the solidification front proceed into the material? and How does the temperature at the surface, at which the heat is being removed, vary in time? The model considered is one-dimensional, a unique fusion temperature is defined, and no properties are temperature dependent.

The heat conduction equations for the solid and liquid phases and the energy balance across the solidification front are developed. The problem is then solved using Goodman's Heat Balance Integral Technique, in which the functional form of the temperature profiles in both phases are assumed a priori. This approximation technique reduces the partial differential equations to ordinary differential equations, in time, which are then easily integrated numerically.

RAYTHEON COMPANY

MISSILE SYSTEMS DIVISION

R.J. Joachim

A PRELIMINARY EXAMINATION OF HIGH TEMPERATURE, SHORT TERM, GRAPHITE/POLYIMIDE STRENGTH

Preliminary short term (less than one minute) high temperature tensile tests of graphite/polyimide composite materials indicated failure stresses for six-ply unidirectional coupons in the range of 199 to 205 ksi at room temperature and between 130 to 150 ksi at 850°F. Relatively smooth strength decreases were obtained for coupons subjected to temperatures between R.T. and 850°F.

Long term (10 min) exposure data showed that the expected strength loss from 600°F to 900°F does not occur.

ABLATION PROPERTIES OF TEFLON AND DUROID-5870

Ablation data from a Mach 5 sled test conducted at Holloman AFB is used to characterize Duroid-5870 and Teflon for Raytheon's AHAB computer program noncharring ablation routine.

Inputting the sled velocity history into the computer program enables selection of a constant ablation temperature with a heat of ablation versus enthalpy difference curve which exactly duplicates the ablation thickness lost in the test. These relationships can then be used for other ablation applications for the two materials.

LARGE SCALE INTEGRATION (LSI) PACKAGING, THERMAL STUDY

Minimum spacing was analytically determined for (1) hermetic chip carriers (HCC's) on alumina substrates and polyimide boards, and for (2) chips in hybrid packages on ceramic substrates and epoxy boards. Guideline curves showing the boundaries between direct air cooling, indirect air cooling, and further improved cooling methods such as liquid cooling are presented for package/chip heat dissipation versus center-to-center package/chip spacing. The analysis assumptions included an inlet air temperature of 50°C at 3000 ft elevation, module pressure drop of 2.0 in. water maximum, and maximum chip temperature of 110°C.

GAS GENERATOR SHELL, PRELIMINARY THERMAL ANALYSIS

Outer and inner shell temperatures for a 2600°F hot gas generator during the last ten seconds of projectile flight are presented as a function of wall thickness, insulation thickness, and combined internal heat transfer coefficient. The lack of analytical techniques to suitably bound the radiative and convective heat transfer coefficients without supplemental hardware tests is highlighted.

ENVIRONMENTAL CONTROL UNIT FOR A HIGH SPEED AIRBORNE SYSTEM

A refrigeration unit is being developed with a subcooler/superheater to maintain components in an airborne system at constant room temperature conditions. A power budget limitation is a major requirement. Both conditioned air and an aqueous glycol liquid must be provided with a maximum excursion of 10°F. Brass board tests revealed that as the condensing temperature was elevated from 120°F to 180°F, the compressor efficiency improved from 35 percent to an asymptotic value of 50 percent. The increasing degrees of subcooling and superheating induced by the fixed heat load forces the evaporator capacity to be compensating, thereby providing the system with increased efficiency. This is obtained by the addition of a relatively small heat exchanger.

GRUMMAN AEROSPACE CORPORATION

R. Kosson, V. Cirrito, and G. Gawronski

MISSILE PLUME IMPINGEMENT HEATING ON THE F-14A HORIZONTAL STABILIZER

An approximate analytic method was developed to establish missile plume impingement heating on the F-14A horizontal stabilizer. The method takes into account the initial geometry of missile and horizontal stabilizer, the missile trajectory, and the missile plume for fully developed thrust at the initial free stream flight conditions. The forcing functions (recovery temperature and convective film coefficient) for aerodynamic heating at any point on the stabilizer surface are calculated as though the stabilizer were immersed in a uniform stream with properties equal to those of the undisturbed plume at that location, allowing for displacement of the plume due to the missile trajectory. The method is shown to provide reasonable agreement with the thermocouple data obtained during a Sidewinder AIM9 missile firing. Predictions using the method have been made for the AMRAAM and Sidewinder AIM9 missiles for the same flight condition, and show only modest differences in anticipated temperature rise.

ACUREX CORPORATION
AEROTHERM DIVISION

B. Laub

HIGH STRENGTH OXIDATION RESISTANT CARBON-CARBON COMPOSITES

Aerotherm has developed new classes of two-dimensional carbon-carbon materials with shear strengths of about 3600 psi and flexure strengths of about 44,000 psi.

The carbon-carbon composites are fabricated using only one to two impregnations with all processing being conducted at approximately atmospheric pressure.

New coatings are being developed as part of an in-house program to prevent oxidation of the high strength carbon-carbon composites. Recent arc plasma studies are multilayered, graded density coatings have demonstrated outstanding potential. One specimen was heated in the Aerotherm arc plasma facility at temperatures up to about 3200°F for 30 min with very little change.

RADOME EROSION TEST STUDY

Advanced tactical missiles are required to fly high-velocity trajectories through natural weather and dust environments which can cause erosion and ablation recession of existing radome materials, affecting radar transmission. The survival of the entire system may be threatened since the erosion-ablation recession of a composite material can approach the radome thickness, and ceramic radomes can fail catastrophically. Therefore, the ability (1) to predict these effects with high confidence, (2) to conduct tests which validate the erosion performance of full-scale radomes, and (3) to evaluate developmental materials for use in radomes becomes important. A study to identify an approach for achieving these three capabilities using existing ground test facilities without extensive modifications has been conducted. Key issues were the relationship between ground test and flight environments, an understanding of the similitude parameters, and how to use ground test data to predict flight performance.

ABLATIVE RADOME MATERIALS CHARACTERIZATION

A study was performed to characterize the thermal and ablative performance of two candidate ablative radome materials: Avcoat 8029 (a particulate-filled polytetrafluoroethylene) and RT/Duroid 5870M (a glass fiber-reinforced polytetrafluoroethylene). A series of tests were conducted in the Aerotherm 1 MW arc plasma generator at simulated tactical missile radome flight conditions. The flat-faced cylindrical samples were instrumented with in-depth thermocouples to define thermal gradients and in-depth thermal histories. An accurate thermal and ablation model is required because transmission characteristics can be affected by changes in dielectric properties with temperature as well as radome shape and thickness.

The results demonstrated that:

1. Modeling these materials as surface sublimers is adequate.
2. The thermal property models developed for both materials provide excellent predictions of material thermal response.
3. Surface temperature and recession rate can be inferred from thermocouple data.
4. Due to the sensitivity of recession rate to temperature, transient effects are important for accurate performance predictions in typical tactical missile radome environments.
5. The thermal/ablative models developed in this program provide excellent predictions of material performance for both Avcoat 8029 and RT/Duroid 5870M.

ABLATION AND SHAPE CHANGE OF DISSIMILAR MATERIALS

A computer code has been developed that predicts the shape change and thermal response of drastically different materials when they are placed adjacent to each other in the thermal protection system. An example is a glass insert (e.g., an antenna window) in carbon-phenolic, under conditions where the glass is a melting ablator. The code, treats the melt layer flow, thermochemical ablation, and transient conduction in the materials. It uses an integral method to predict the free stream-boundary layer interactions, such as shocks and separation that occur when steps and cavities result from the differential recession.

PARTICLE IMPACT EROSION IN ROCKET NOZZLES

A comprehensive methodology has been developed to predict the total recession in solid propellant rocket'nozzles. The contributions of both particulate erosion as well as thermochemical ablation are taken into account. This methodology is divided into two parts: one for the supersonic region and the other for the subsonic and transonic regions of the nozzle.

A number of experiments were carried out to collect data and correlate the effects of particulate erosion. Supersonic region impact was characterized by experiments in the Dust Erosion Tunnel at AEDC and using small solid rocket motors at the Aerojet Strategic Propulsion Company test facility. Subsonic/transonic region impact was characterized by experiments in the arc plasma generator at Aerotherm. The latter set of experiments were conducted with molten aluminum and aluminum oxide particles, and hence accounted for the effects of mechanical and chemical erosion on carbonaceous surfaces.

The analytical effort on this program consisted of the development of models for erosion and related phenomena, such as debris layer shielding. Flowfield codes were selected to determine the location and conditions of impact. For the subsonic and transonic region, an existing two phase flow code was extensively modified to account for the effects of chamber and grain geometry on particle trajectories. Furthermore, the erosion models were incorporated into the charring material ablation (CMA) code to account for the combined (coupled) effects of ablation and erosion.

KINETIC RATE CONSTANTS FOR NOZZLE RECESSION OF PITCH-FIBER CARBON-CARBON COMPOSITES

With the advent of low-cost, mesophase (pitch) fibers, the recession thermochemistry in a solid-rocket motor environment of carbon-carbon composites with these pitch fibers has been investigated. The kinetic rate constants have been determined for the recession of a pitch-fiber composite exposed to various nozzle test gases in the high-temperature reactive environment of the Aerotherm 1 MW arc plasma generator. From the measured recession, temperature, and pressure, the correlation coefficients were determined for the reactions between graphite and H_2O, CO_2, and H_2.

These results indicate that the difference between the mass removal rates of a pitch-fiber composite and a PAN-fiber composite is dependent upon the nozzle surface temperature (type of propellant) and the mass transfer coefficient. Direct comparison of the recession rates of these two materials requires a complete nozzle analysis accounting for these parameters. Analytical prediction of the recession of nozzles with a pitch-fiber composite and a PAN-fiber composite showed good agreement with the measured recession of two of three actually fired nozzles. Sensitivity studies showed the importance of radiative heat loss to the insulation in a motor with large free volume and the effect of surface roughness on recession.

CALSPAN/AEDC DIVISION*

R.K. Matthews

STORES HEATING TECHNOLOGY

This activity is concerned with defining the thermal environment of missiles and/or bombs (stores) carried on supersonic aircraft. The specific technology to determine heating rates and temperature for various flight conditions has been documented in many reports (e.g., AEDC-TR-78-46). This past year's activity has centered around the captive carriage flight testing of an instrumented AIM-9 missile. The instrumentation consists of about 50 heat transfer gages which provide temperature and heating rate measurements. These data are recorded on a "stand-alone" internally carried data recording system (AEDC-TMR-81-V2). Data from three F-111 flights and one F-15 flight are currently being analyzed. One of the primary uses of this data is correlation with existing wind tunnel data. However, the prescribed flight profiles required to produce high quality heat transfer data have been difficult to obtain. The extensive temperature measurements are providing a good "data bank" for defining the thermal response of the missile outer skin during typical high speed flights.

AMRAAM TECHNOLOGY PROJECT

The aerothermodynamic environment of the AMRAAM is being studied both analytically and experimentally. In addition to defining the AMRAAM pressure and heating distributions, several brief feasibility studies have been conducted which are of interest to missile developers. These studies are discussed below:

Boresight Error Measurements on Aerodynamically Heated Radomes

Most boresight error measurements have been obtained with the radome at room temperature. However, Weckesser and Frazer have shown that a heated radome can produce significantly different results. At AEDC, a study is underway to show how boresight error measurements can be obtained using a wind tunnel to produce a good simulation of the flight temperature levels and distribution on the radome. Ten different approaches have been considered and the more promising ones are currently

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*The work reported herein was performed by the Arnold Engineering Development Center, Air Force Systems Command. The work and analysis was done by personnel of Calspan Field Services, Inc./AEDC Division, operating contractor for Aerospace Flight Dynamics Testing at AEDC. Further reproduction is authorized to satisfy needs of the U.S. Government.

being defined in detail in preparation for a test in FY-82. This test will be conducted in the new true temperature aerothermal tunnel with expertise on the radar aspects of the test being provided by General Dynamics and Georgia Tech. personnel.

Environmental Testing of Operational Missiles

The facilities at the Navy's Pacific Missile Test Center do an admirable job of missile environmental testing for the captive carriage model. However, operational checkout from launch to target is normally done by actually launching the missile which is very costly. A feasibility study just completed investigated the use of large wind tunnels to provide the simulated supersonic flight environments (temperature, pressure, etc.) for actual missiles. This study showed that, in general, the supersonic flight environment can be simulated, missile post launch operation can be verified, and that these tests are relatively inexpensive.

Rain Erosion Simulation in a Continuous Flow Wind Tunnel

Rain erosion testing is normally accomplished on a sled track or in a range (e.g., VKF Range G). One primary disadvantage of this type of testing is the relative short test time available. In an effort to provide longer test times and less expensive tests, a brief feasibility study has been completed on the addition of "rain drops" to continuous flow wind tunnels. This study concentrated on three specific areas:

1. injection of water droplets into the flow;
2. acceleration of the droplets to the air velocity; and
3. measurement of the droplet size, density, and velocity in the region of the test article.

Of the three areas studied, the second is clearly the one presenting the biggest technical challenge.

Wind tunnel nozzles, as presently designed, accelerate the water drops at too high a rate which produces shear forces that fragment the drops into a mist. New nozzle designs are required and the technology necessary to design this type of nozzle is available if there is sufficient justification.

REVIEW OF FIREBOLT THERMAL ANALYSIS

The Firebolt is a high altitude, high speed (M_∞=4) target vehicle which is currently in development under the sponsorship of the System Division at Eglin AFB. At their request, a review of the contractor's thermal analysis was performed. No major aerothermal problem areas could be identified, however, this review did illustrate the need for an industry wide standard on thermal analysis. The work done by Stultz and Kipp ("Structural Design Temperature Manual," McDonnell-Douglas, St. Louis, AFWAL-TR (to be published)) presents a good foundation for the development of such a "standard."

HEATING TESTS AT AEDC/VKF

As in past years, a number of different tests have been conducted for several DoD sponsors. Specifically, thin skin heating data have been obtained on the shuttle orbiter, the MX missile, the ACMRV (Aerodynamic Configurations for Maneuvering Reentry Vehicles), and others. The VKF data recording system has recently been modified from 98 to 256 channels and other changes in testing techniques have helped to hold down test costs.

MATERIALS EVALUATION TESTS

Evaluation of the thermal response and survivability of thermal protection materials continues to increase particularly now that the new aerothermal tunnel is operational. This facility provides duplicated Mach 4 flight conditions with a total temperature of 1180°F.

VOUGHT CORPORATION

J. Medford

CRYOGEN SUPPLY SYSTEM FOR HIGH ALTITUDE MISSILE SENSOR

The objective of this effort was to develop a system for supplying cryogen to a high altitude missile sensor. The missile is launched from a carrier aircraft to orbital velocity and altitude. A cryogen supply system was developed to cool and maintain sensor components within their required temperature limits. A supercritical helium configuration was selected to provide maximum thermal margin and minimum system weight. The system is comprised of two flight dewars and their associated cryogen transfer hardware to store and supply coolant to the sensor. The carrier aircraft equipment dewar is located in the carrier aircraft and supplies cryogen during captive flight. The upper stage dewar is located in the missile upper stage equipment compartment and supplies cryogen during missile flight. The system features separate fill ports for each dewar to permit both dewars to be filled simultaneously. The configuration also places the upper stage dewar in a standby mode during captive flight to maximize the amount of cryogen available to cool the sensor during missile flight.

UNITED TECHNOLOGIES

CHEMICAL SYSTEMS DIVISION

P.F. Melia

ASALM TPS DURABILITY TESTS

The ASALM TPS durability tests were concluded with four tests of identical geometry, center dump, and MDAC configuration combustors. Tests 14 and 15 used 3DQP linings and tests 16 and 17 used DC93-104 linings. Similar low-high-low, 435 sec duty cycles were tested with the exception of test 14 which had the terminal 65 sec dive/dash replaced by an additional 215 sec of high altitude cruise.

DC93-104 MODELING

The DC93-104 tests corroborated the effectiveness of the CMA/ACE/boundary layer thermal model for thick (0.5 in., 0.6 in.) DC93-104 and duty cycles with significant reactive oxygen in the combustion product species. Passive thermal models are still felt to be acceptable for thin DC93-104 and stoichiometric fuel-to-air ratios.

3DQP PERFORMANCE IN RAMJET COMBUSTORS

The 3DQP tests revealed a variability in apparent char conductivity from one TPS part to the next. Small variations in virgin part porosity and combustor oxygen concentration are tentatively believed to result in significant variations in char conductivity and survivability.

LIFRAM INSULATION PERFORMANCE

The LIFRAM IRR booster was successfully fired after modifications to combustor, nozzle, and ignitor insulation to provide extra protection in regions of local high velocity flow. The modified insulations used included carbon phenolic, DC93-104, and carbon-filled hydroxy-terminated polybutadiene (CFHTPB). The latter material appears to be greatly superior to DC93-104 in the LIFRAM booster environment.

MARTIN MARIETTA CORPORATION - ORLANDO DIVISION

T.V. Radovich

CHARACTERIZATION OF GASJET NOSE TIP FOR REENTRY ENVIRONMENTS

The gasjet nose tip (GJNT) concept was developed in the mid-1970's as a compact, reliable, low-cost alternative to transpiration cooling for severe trajectory environments. In the GJNT concept, 2000°F gas, generated by the combustion of a conventional solid propellant grain, is discharged forward, typically through a single sonic orifice at the outlet of a refractory nose tip, into the stagnation region. Here the warm gas expands, forming a surrogate stagnation region. The coolant gas then mixes with the local airstream and flows aft in the boundary layer to protect the nosetip sidewalls both thermally and chemically.

Recent testing of GJNT systems have focused on erosion resistance, as well as on thermal performance. In late 1980, erosion testing of GJNT models was performed at 16,000 ft/sec velocity in man-made snow (LWC=1.0 gm/m^3) and dust (300μ, 0.88 to 2.1 gm/m^3) environments at AEDC Range G. The snow environment produced negligible erosion, while the dust provided sufficient data to verify nose tip analytical erosion resistance methods. In-house light-gas gun tests with single 3/8 in. particles have also demonstrated significant large particle impact capability. Thermal characterization has recently centered on angle-of-attack testing at Mach 6.7 in NASA Langley's HTST 8-ft tunnel. Data, including IR scanner measurements, are in final reduction.

HEAT REMOVAL FROM DENSELY PACKAGED ELECTRONICS

The trend toward more compact, lighter weight weapon systems is dictating increased component and power dissipation densities in future electronic packages. Conversely, lower component junction temperatures are being demanded in order to increase component reliability. In order to reconcile these requirements, research has been directed toward evaluating advanced techniques for removing heat from densely packaged electronics.

Recent cooling studies encompassed performance evaluations of PC cards with metallic cores and sandwiched heat pipe cores, alternate card retainer devices, and card guide to cold plate conductance schemes. Tests of cored modules with a distributed load of 40w demonstrated center-to-edge temperature differences of from 19°C for aluminum cores down to 3.6°C for heat pipe cores. While copper cores proved just as effective as heat pipe cores on an overall performance basis, the weight penalty associated with the copper was 3 times that of the aluminum heat pipe cores.

On the component level, another study established an internal cooling technique for high dissipation power amplifier hybrid chips. This technique incorporated the use of a copper pad between the chip and the substrate in a standard package. By using a copper pad with an area greater than that of the chip and of sufficient thickness to produce a uniform temperature, reductions in chip junction temperatures of from 145°C to 105°C could be achieved.

SPLIT CYCLE CRYOGENIC COOLER IMPROVEMENTS

Cryogenic coolers are in integral part of IR imaging systems because detector elements must be maintained between 80°K and 100°K in order to achieve usable signal-to-noise ratios. Statistically, however, state-of-the-art coolers have a shorter "in-spec." life than the system's solid-state electronics. As a result, continuing research is being done with the goal of increasing cooler longevity. Studies to improve cryogenic cooler reliability address both refinements to current designs and advanced concepts. Areas applicable to current designs include contamination control (gaseous and particulate), seal improvements, improved wear-resistant materials, and improved processes and controls. Basic technological improvements such as crankcase isolation, positive displacer stroke control, and a linear drive compressor are also being pursued.

SHIPBOARD HATCH ANTI-ICING SYSTEM DESIGN AND TEST OPTIMIZATION

For on-deck equipment exposed to a Navy shipboard environment of -18°C and 75 knot relative velocity, icing rates of from 2 in./hr to 6 in./hr are not uncommon. As part of the vertical launching system (VLS) effort, a hatch anti-icing system was designed and tested using a facility developed in-house. Because each VLS magazine incorporates 61 missiles cell hatches, maintaining the hatches completely free of ice was not feasible from a power consumption standpoint. Instead, the design concept involved preventing ice formation only along hatch edges and exposed moving parts where bridging to the deck would restrain the hatch opening. The system selected used metal clad tubular heaters embedded along hatch edges and cartridge heaters installed in all hatch brackets. Design power levels were obtained by dividing the cell hatch into discrete nodes with connecting resistances using the SINDA thermal electrical analog program and considering convection as the dominant mode of heat loss. The resultant design power level along the periphery of the cell hatch was 24w/linear inch.

A facility was constructed within the MMO building's J environmental chamber which allowed for the optimization of heater power levels. The facility consisted essentially of a low speed wind tunnel with sufficient cross-sectional area to provide for full-scale hatch testing and a water delivery system capable of providing intermittent, reasonably uniform flow on the hatch. Systems were also incorporated to vary heater power levels and to measure hatch opening torque. Testing verified that while some very localized bridging occurred, the design heater power levels allowed hatch opening well below the motor torque limit. Further testing proved that a 15 percent power reduction still offered an ample safety margin. This was attributed, to a large degree, to the insulating effect of the ice which formed in the center of the hatch.

KEVLAR THERMOPHYSICAL PROPERTIES

Kevlar is a highly modular organic fiber used to reinforce matrix resins, primarily epoxies, in a variety of applications. Its strong, lightweight, durable characteristics make it an ideal candidate for use as a motorcase material for high performance missiles such as the Pershing II. Because Kevlar is a new material for this type of application, thermal tests were performed to ascertain its performance in a missile aerothermodynamic environment.

Thermal tests of Kevlar 49/HBRF55A resin composite encompassed thermophysical property tests and high heat flux or shear tests. Thermophysical properties obtained were density, thermal conductivity, specific heat, and thermal gravimetric measurements in nitrogen and air. The latter measurements indicated that the Kevlar composite starts degrading at about 460°F with rapid degradation occurring above 800°F. Heat flux tests were performed at the MMO Ramburner Facility under quartz lamps. Cold wall heat fluxes for the ramburner tests were from 25 to 35 Btu/ft^2 sec. In this environment, the material formed a nap, much like a carpet, as the resin decomposed. Based on the ramburner test data, an ablation temperature of 800°F and a heat of ablation of 300 Btu/lbm provide the best fit of the Kevlar 49/HBRF55A resin database.

DUROID 5650M/FIBERGLASS RF ATTENUATION TESTS

Tests were performed to determine the RF attenuation of Duroid 5650M/fiberglass when subjected to the thermal environments of the MMO Ramburner Facility (cold wall heat flux of 145 Btu/ft^2 and recovery temperature of 3100°F) and the Avco 10 MW Plasma Arc (cold wall heat fluxes $\approx$1120 Btu/ft^2 and stagnation enthalpies = 2540 Btu/lbm). The tests were made at Pershing II frequencies of interest using circular polarize transmit and receive antennas. Measurements were also made through slip-cast fused silica as a control.

The test results revealed no carbon-flourine interaction or other surface reactions of an amount to cause measured RF attenuation at the frequencies and temperatures tested.

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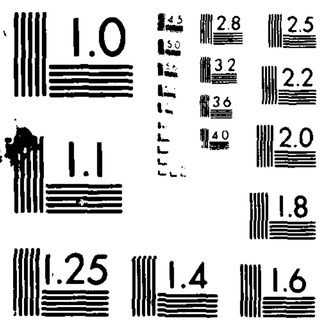

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

HEAT TRANSFER PANEL RECOMMENDATIONS TO NAC

1. RECOMMENDATION:

(HEAT TRANSFER AND EROSION OF SURFACES EXPOSED TO SOLID ROCKET EXHAUST):

Analyze data from test programs conducted in FY-80 and FY-81 that used scale model solid rocket motors producing representative chamber pressures and temperatures to simulate aluminized propellant boosters (i.e., SM-2, Harpoon, Tomahawk, etc.) for evaluating shipboard, ground and ship VLS platform design heating rates, erosion, and protection requirements.

Establish relationships existing between heat flux and erosion rates as a function of material type alumina deposition, axial and radial location in the plume to the extent that heat transfer coefficients and erosion rates can be predicted. Modify or otherwise correlate existing free expansion plume profile computer codes to include both heat flux and erosion. Continue the experimental and analytical program to develop material response characteristics and response to the solid propellant rocket exhaust.

BACKGROUND:

Insufficient heating rate data are available to adequately define exhaust plume heat flux as a function of position in the plume or to calculate heat transfer coefficients for direct and indirect impingement of exhaust gases from solid propellant motors. In addition, some propellants are aluminized for increased performance. Impingement of this aluminized exhaust causes surface erosion which may be of more serious concern than the thermal results. No adequate method of analyzing surface erosion against different materials exists. Analysis of structure heating and environmental protection requirements requires a method to evaluate the thermal and erosive effects of plume impingement.

2. RECOMMENDATION:

(MISSILE EXTERNAL ABLATOR/INSULATOR):

An investigation should be conducted to determine the benefits of using an ablator or insulation on the external surface of missile structure, thereby allowing use of an aluminum structure. Application should be directed to the missile mainbody. This effort should be for high supersonic and hypersonic tactical missiles, with emphasis on solid rockets, but also including ramjets. The investigation should consider existing materials as well as potential candidates in determining the trade-offs in weight, cost, fabrication, and other factors. The study should identify for what applications (Mach number, flight time, propulsion type) use of an ablator or insulation is beneficial. Factors, such as low thermal conductivity and gas dynamic shearing stress capability, are to be considered. This should be an overall planned and coordinated effort consisting of a study, development of candidate materials and concepts, testing and concept demonstration.

BACKGROUND:

An ablator of insulation on the external surface has been considered and used in past missile designs. However, a comprehensive and organized investigation has not been undertaken nor documented on the feasibility and benefits of such thermal protection. Consequently, new and innovative thermal protection concepts have not been given the attention necessary to develop them into viable candidates. With the increased consideration being given to higher speed there is a potential for a greater payoff for using an external ablator or insulation to maintain the structure at a low temperature.

3. RECOMMENDATION:

(EROSION ENVIRONMENT DESIGN CRITERIA):

A comprehensive program should be initiated to define realistic particle erosion environments with emphasis placed on probability of occurrence and including design criteria. This effort should draw upon environmental definitions existing for strategic systems and expand on recently completed efforts on storm modeling, specifically rain rate and path length statistics. Fundamental parameters that need to be addressed are: rain rate, liquid water content, particle size, spatial distribution, and geographic and seasonal variation. Results should be presented in a statistical format that allows program managers to make design decisions based on probability of occurrence.

BACKGROUND:

A crucial factor in the design and qualification of erosion resistant aircraft and missile radomes is the definition of realistic particle erosion environments. While rain is the most commonly addressed cause of erosion, ice, snow and dust (including that in a nuclear cloud) can also cause damage in high speed flight. The rain environment specified in MIL-STD-210B is not comprehensive enough and is too severe for random design purposes. Design criteria are needed that specify probabilities of occurrence and consider the ability of seekers to "see" through such environments.

4. RECOMMENDATION:

(PARTICLE EFFECTS ON AERODYNAMIC HEATING):

It is recommended that experiments be conducted to measure the heating rate at up to M = 4 on radome materials in an erosion-ablation environment.

BACKGROUND:

Advanced tactical missiles will encounter rain, snow, and possibly dust at Mach numbers up to 4 for approximately 30 sec. An accurate knowledge of the heating in these environments is important because the survival or performance of components like composite radomes is threatened by excessive erosion-ablation, which becomes strongly dependent upon heating in the M = 2 to 4 regime. An RT/Duroid 5870 radome, for example, is predicted to have almost 0.4 in. recession during a M = 4 flight through a rainstorm. The heating affects this recession prediction in two ways: (1) directly via ablation, and (2) indirectly through its effect on the temperature dependent material properties that control erosion.

However, the heating in an erosive environment is not deducible from current data because erosion and ablation are intrinsically coupled and the measurement of another variable is needed in order to infer both the erosion mass loss rate and the heating.

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1981 REPORT TO THE

NAVY AEROBALLISTICS COMMITTEE

FROM THE

LAUNCH DYNAMICS

PANEL

INTRODUCTION

The panel met at the David W. Taylor Naval Ship Research and Development Center on 5-7 October 1981. Members present reported on accomplishments in their respective activities during the past year and formulated technical recommendations for consideration by the NAC. These are reported here.

The attendees were:

Dr. William B. Baker, Jr.	CALSPAN/AEDC
Mr. R. Carson	Naval Air Development Center
Mr. G.F. Cooper	Pacific Missile Test Center
Mr. L.L. Gleason	Naval Weapons Center
Mr. E.F. Lucero	Johns Hopkins University Applied Physics Laboratory
Mr. A. McEwan	Northrop Corp., Ventura Division
Mr. K.A. Phillips	David W. Taylor Naval Ship Research and Development Center
Mr. P. Pondrom	McDonnell-Douglas Astronautics Co.
Mr. C. Matthews	Air Force Armament Test Laboratory, Eglin, Florida
Mr. K. Okauchi (Chairman)	Naval Weapons Center
Mr. R.M. Rogers	Hughes Aircraft Co.
Mr. H.R. Spahr, Jr.	Sandia Laboratories
Mr. R. Stallings	National Aeronautics and Space Administration Langley Research Center
Mr. W.A. Walker	Naval Surface Weapons Center White Oak Laboratory
Mr. J.J. Yagla	Naval Surface Weapons Center Dahlgren Laboratory

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

K.A. Phillips

FUEL TANK JETTISON TEST FOR F-16

The Center's effort in Launch Dynamics has been at a relatively low level during the past year. A test program to study the jettison characteristics of a fuel tank from the F-16 aircraft was done in the 7-ft × 10-ft transonic wind tunnel. This dynamic drop test covered eight drop conditions at Mach numbers of 0.7 and 0.9.

CAPTIVE TRAJECTORY SYSTEM MISHAP

Preparations for three captive trajectory system (CTS) tests were completed; however, a major fire in an electronic cabinet damaged the control unit for the support system. One of the test programs was postponed while the others were either cancelled or transferred to another facility. The control console has been repaired and checked out in preparation for completing the postponed test.

SUMMARY PAPER

A paper entitled "Recent Experimental Efforts in Store Separation at DTNSRDC" by K.A. Phillips was presented at the Navy Symposium on Aeroballistics.

NAVAL SURFACE WEAPONS CENTER/DAHLGREN, VIRGINIA

J.J. Yagla

VERTICAL LAUNCHING SYSTEM

The management of the hot rocket exhaust has been of particular concern in the development of the vertical launching system (VLS). Special materials have been required to protect the launcher and ship from the exhaust. The design of the VLS to fire the Standard missiles has been particularly critical due to the tremendous temperatures and quantity of exhaust from the missile and the additional fact that the exhaust must be safely managed within the ship.

The analysis of the internal ballistics of missile launching systems is a challenging engineering problem requiring the application of a variety of engineering techniques and the development of complicated mathematical models. The calculations first require a detailed knowledge of the rocket exhaust product set as the material leaves the nozzle of the rocket motor. Very sophisticated numerical techniques and large computers are required to analyze the dynamics of the gas motion through the exhaust management system. Two-dimensional, nonsteady, compressible flow analyses have been useful in developing an understanding of the flow processes, and have provided velocity fields for the heat transfer analysis. Quasi one-dimensional non-steady flow techniques have been useful for calculating wave motion through the system, and determining mechanical design criteria. The thermal response and performance of the protective materials used in the system have been analyzed by adapting turbulent convection heat transfer models for use with the quasi one-dimensional gas dynamics analysis. These models are described in the companion paper presented to the Heat Transfer Panel.

The flow field in the actual launching system is fully three-dimensional, and at present there are no computer techniques capable of solving such a problem. However, the two-dimensional modeling has proven to be an invaluable tool for developing a basic understanding of the relative importance of the various phenomena that structure the internal flow. It is shown that even a quasi one-dimensional model is sufficient to obtain very good design data.

NAVAL WEAPONS CENTER

L. Gleason

This report summarizes store separation and related activities during the past year at the Naval Weapons Center. A summary of planned activity for next year is also included.

STORE SEPARATION ANALYSIS

A contract has been let for a modification to the NEAR subsonic store separation computer program (NEAR Code). This is a one-year contract with Auburn University and involves incorporating most of the recommendations into the Code. This should lead to improved modeling of the forces and moments experienced by a store carried on or close to a Triple Ejection Rack (TER). More accurate modeling is required of the flow field at the position to be occupied by the bottom store with the two shoulder stores present. Also, full mutual interference among all three stores and a rack must be taken into account in determining the loads on the bottom store. In addition, provision will be made for inputting experimental data for the store alone in the free stream and accounting for movement of the separation location on a boattail afterbody based on the local angle of attack at the afterbody position.

A series of equations have been developed for the store input data requirements for the NEAR Code. Input requirements are reduced to store physical dimensions for pylon alone, TER, or MER. These have been developed for the A-7 and A-6.

An effort to identify user modifications to the NEAR Code was initiated. Letters were sent to known users of the code requesting a description of any modifications made to the code. Upon receipt of British input these will be consolidated and published.

An effort to convert the NEAR Code from Fortran V to ASCII Fortran has taken considerable time. The source distribution program is converted and has been checked out. The trajectory program has been converted and run, but the answers differ from the Fortran V runs. Investigation into these differences is now underway.

WIND-TUNNEL AND FLIGHT TESTS

The BIGEYE was a 6.2 program that was cancelled in the late 1960's and recently revived with the idea of immediately going into production. Needless to say problems were encountered during separation tests which necessitated "quick fixes." Wind-tunnel tests were conducted in February 1981 at the DTNSRDC Transonic Wind Tunnel. Tests were conducted on the basic BIGEYE and modified BIGEYE configurations having various combinations of modified stub-fins, fins, and afterbody flare in an attempt to define a more stable configuration.

Test results show the basic BIGEYE configuration with fins stowed to be less stable than a ROCKEYE. With the change to the wedge fins (MOD) an increment of stability is realized. Addition of the flared afterbody resulted in stability at the lower angle of attack equivalent to the ROCKEYE II. Movement of the center of gravity from 47 in. to 44 in. provides a further positive increment in stability over a wider angle-of-attack range. This could have a significant impact on the launch characteristics up to the time of fin deployment. In the follow-on flight tests the above changes were incorporated. In addition, the time delay to fin opening was decreased. Flight tests of the modified BIGEYE were successful in the regime where problems had been experienced. Simultaneous drops of the modified BIGEYE and ROCKEYE show the BIGEYE with flared afterbody to be more stable prior to fin deployment than the ROCKEYE. However, due to the "quick fix" approach taken (all modifications incorporated at one time), it is not possible to attribute the improved separation characteristics to any one or to a combination of modifications.

PLANNED ACTIVITIES

Completion of the NEAR Code conversion to ASCII Fortran is necessitated by the installation of a new UNIVAC computer at the Naval Weapons Center. Some time in 1982, Fortran V no longer will be supported.

Development of an F-14 model for the NEAR Code is planned for FY-82. This model is required to support the ACIMD program underway at NWC.

The generalized store input equations will be developed for the F-18 and F-4. These equations should eliminate store input errors and could easily be incorporated into the computer program.

A report will be published describing the user modifications and/or improvements made to the NEAR Code.

PACIFIC MISSILE TEST CENTER

G.F. Cooper

AIRCRAFT CHANGE CONTROL BOARD

During FY-81 the PMTC Aircraft Change Control Board approved a number of external store modifications for use on PMTC aircraft. The changes approved this year are given as follows:

ACCB Number	Title or Subject
81-019	Approval to fly the Augmentation Light Pod on all PMTC EP-3A and A-6 aircraft (a minor change to the nose of the existing pod was approved to a maximum airspeed of Mach 0.9).
81-025	Nose Section Modification to ALQ-167 (an addition of a bluff radome to the underside of the nose, using the same basic pod as the DLQ-3 METE series; cleared to a maximum airspeed of Mach 0.6; no jettison allowed)
81-026	Certification of DLQ-3B Tulsa Pod (for use on the S-2 aircraft, emergency jettison only; remove pod prior to wing fold)
81-028	Flight Clearance for NWC Instrumentation Pod S/N 1001 on A7-E Bu. No. 160710 (associated with AGM-88A program, cannot be jettisoned)
81-033	Rushton Tow Target Flight Clearance (evaluated by the Threat Simulation Department. Built by Flight Refueling LTD, England; Low Level Height Keeping Target--simulates sea skimming missiles over ranges from 500 ft down to 20 ft above sea level with height keeping accuracy of $\pm$7 ft. Contains radar altimeter and pitch plane height control system)
81-042	F-14A Certification to Carry AFH-IVB Photo/Video Pod on BH 224 and BH 226

THREAT SIMULATION DEPARTMENT

BQM-34 A/S to Support the RAM Program

A modified nose BQM to be flown by the PMTC Threat Simulation Department in support of the Rolling Airframe Missile (RAM) test program. The nose contains an antenna dish which will train on a ground beacon as the BQM flies by. This is not the first aerodynamic modification of the BQM. The RAM project configured nose was originally flown by the Army.

Tow Target Deployment Reel for the QF-86

A tow body deployment reel originally flown on the BQM-34A is being repackaged to go on a wing pylon of the QF-86.

ARNOLD ENGINEERING DEVELOPMENT CENTER, AFSC
CALSPAN/AEDC DIVISION

W.B. Baker, Jr.

AERODYNAMIC TESTING

During the period since the last panel meeting, 20 wind-tunnel tests have been conducted producing store separation or carriage loads data. Documentation for these tests is included in the Bibliography. Most of the testing involved separation trajectories or grid surveys using the Captive Trajectory Support (CTS) system. Other tests include dynamic drop, captive loads on stores in the carriage position, or free-stream tests of stores.

Grid and CTS tests were conducted on fighter, bomber, VSTOL, and attack aircraft. Most of the testing involved the F-16 and F-15 aircraft with the rest of the tests divided among the F-14, F-18, AV-8B, F-4E, F-111, and the Rockwell Multirole Bomber. The primary stores for which CTS or grid data were obtained were gun pods, guided bombs, and missiles. The bomber test was primarily directed to the measurement of flow fields around the internal and external store carriage positions. Some unique tests were conducted to determine specialized effects such as store release from the top of an aircraft wing, store-store interactions for munitions separating from a dispenser, free-stream aerodynamics of loaded racks, and velocity flow fields as determined by a three-component three-color laser velocimeter.

In the test to determine store-store interactions, free-stream grid and aerodynamic flow field data were acquired on scale models of the Anti-Material Incendiary Submunition (AMIS). Aerodynamic flow field data were acquired on the AMIS in the presence of the Low Altitude Dispenser (LAD). Flow field data were also taken with a model of the LAD bay closure panel at various positions relative to LAD model. To determine the flow field effects of one AMIS model upon another, an AMIS model was suspended by wires and a grid survey was made using a second AMIS model mounted to the CTS system. Flow field data were acquired at Mach numbers 0.4 and 0.8 at submunition and panel incidence angles, relative to the LAD, of 0 to 90 deg.

The test using a laser velocimeter (LV) to make measurements in the transonic flow field of selected aircraft-store combinations is currently in progress. Model components used in the test include a wall-mounted half fuselage with a side mounted inlet, a 45-degree swept wing with a 60-degree swept pylon and TER and three sting-supported MK-83 stores. One store is mounted on a six-component balance and can be tested with or without fins. The other two stores are dummies with no fins. The LV flow field and/or store force and moment measurements will be obtained.

Two tests have been conducted in support of facility improvement projects. One test was to implement the continuous motion technique, via the velocity control mode of operation obtaining captive separation trajectories. This test was in support of a technology project. Separation trajectories were obtained for the GBU-8/B and AGM-65A from the F-16 aircraft. Data were obtained using the facility computer in the position control mode and the trajectory generator computer and its associated hardware in both the position control and velocity control modes for use in verifying switchover to the new testing technique. The other test was conducted to determine the effects of humidity in the tunnel on CTS determined trajectories. Aerodynamic grid and captive trajectory data were obtained for the GBU-15 (CWW) at Mach numbers from 0.9 to 1.3 and 2.0, airflow specific humidities from 0.0014 to 0.0070 lbm H_2O/lbm air, and tunnel total temperatures from 85 to 157°F. Trajectories and flow field surveys were initiated from a pylon station of the F-15 aircraft model.

TECHNOLOGY ASSOCIATED WITH STORE SEPARATION OR CARRIAGE LOADS

Two technology projects involving three separate studies relating to store separation or carriage loads are currently underway at AEDC. One project involves the development of a semiempirical prediction technique for the prediction of total loads and the distribution of airloads on a store in the interference flow field of an aircraft. The other project involves several activities directed toward the improvement of separation testing in the wind tunnel.

DISTRIBUTED LOADS TECHNOLOGY

A semiempirical code has been developed which provides quick and reasonably accurate predictions of aerodynamic loads and their distribution on complex store configurations for a wide range of flight conditions in the free stream. The code has been extended to provide the capability of making predictions in an interference flow field. Areas where further methodology refinements may be desirable have been identified.

An experimental technique has been developed to measure load distributions on stores in a wind tunnel by using a segmented model with separate balances for each segment. The validity of the technique was established by comparing the data from a large-scale four-segment model with data from a large-scale pressure model and was extended to a smaller scale using a three-segment model of the same configuration. A small-scale segmented model will be tested in the carriage position on an aircraft, providing data for validation of the interference flow field distributed loads prediction technique.

This work was reported in AIAA Paper 81-1896 and the wind tunnel test was reported by Hodges, Feb 1981.

STORE SEPARATION TESTING IMPROVEMENTS

Two phases of this project are relevant to the activities of the Launch Dynamics Panel. A study is continuing for the development of small noncontact model alinement position sensors for use in the Captive Trajectory Support (CTS) systems in the wind tunnels at AEDC. The current study is to determine if smaller optical sensors than presently used in Tunnel 4T or fiber optic systems are available which can be used easily in multiple-carriage-rack models. System components have been procured and a laboratory evaluation is underway.

Work also continues on the development of a trajectory prediction technique based on the regression analysis of data obtained from trajectories generated by the CTS system in the wind tunnel. Regression curve fits of the interference forces and moments on the store attributable to the presence of the aircraft will be used along with regression curve fits of freestream store aerodynamic data to provide aerodynamic inputs to a six degree of freedom trajectory generation computer program. A side benefit of this study has been the development of an empirical trajectory completion technique which allows the completion of prematurely terminated trajectories. Further development of the trajectory completion technique is required and planned for next year.

NASA LANGLEY RESEARCH CENTER

R.L. Stallings, Jr.

STORE SEPARATION FROM CAVITIES AT SUPERSONIC SPEEDS

Conformal or submerged carriage of stores is being considered for supersonic aircraft in order to minimize aerodynamic heating, aerodynamic drag, and radar detection; however, very little information is available in the literature to evaluate store aerodynamic characteristics during separation from such carriage configurations. Therefore, a wind-tunnel program was initiated at NASA Langley Research Center to investigate the aerodynamic characteristics of typical store configurations during separation from cavities of various shapes and various depths. The cavities were located in a splitter plate that spanned the low Mach number test section of the Unitary Plan Wind Tunnel. Tests were conducted at Mach numbers from 2.36 to 2.86.

Results from these tests show that cavity shape and cavity depth can have strong effects on store separation characteristics. For example, force and moment measurements obtained using a typical wing-control missile model showed that for "shallow" cavities (typical depths for conformal carriage), a silhouette cavity matching the silhouette of the missile model resulted in far superior separation characteristics than a simple box cavity. However, for "deep" cavities (typical depths for internal carriage), cavity shape had little effect on the missile separation characteristics which were comparable to the shallow-silhouette cavity results. Future tests are planned to determine the separation characteristics of several generic store configurations in the near field of various "shallow" cavity configurations. Tests are also planned to determine the cavity depth to length ratios corresponding to the transition from "shallow" cavity to "deep" cavity separation characteristics.

JOHNS HOPKINS UNIVERSITY/APPLIED PHYSICS LABORATORY

E.F. Lucero

DEVELOPMENT OF VERTICAL LAUNCHING SYSTEM (VLS)

The JHU/APL is the Weapon/Systems Missile Integration Advisor to the NAVSEA VLS Program Manager. The Technical Direction Agent is the Naval Surface Weapons Center/Dahlgren Laboratory. The VLS has been in full-scale development at Martin Marietta Corporation (MMC), Orlando, Florida, since June 1977. Since that time, a baseline Preproduction Model (PPM) of VLS, which consists of a five-cell module and an eight-cell module, has been designed and fabricated to interface with Aegis ships and Standard missiles (SM). The major portion of the critical testing has been accomplished and the technical principles have been demonstrated.

Testing at the White Sands Missile Range (WSMR) with the five-cell module has included two SM-1 Blast Test Vehicles and one SM-1 with MK 56 DTRM restrained firing. These tests demonstrated that the VLS Gas Management System could safely vent the exhaust of SM for a normal launch or in an inadvertent restrained firing.

During the past year successful launches have been made at WSMR from the baseline VLS of one single SM Launch Test Vehicle (LTV) on 7 November 1980, three LTV's fired sequentially on 27 November 1980, and two AEGIS/SM-2(MR) Block I missiles on 22 January 1981 and 6 February 1981. The guided SM-2 Block I missiles were successfully flown against nonmaneuvering BQM-34 targets.

The first launch of a Tomahawk missile from an experimental TOMAHAWK-capable VLS(T) was conducted on 28 November 1980 from Point Mugu, Pacific Missile Range. The launch was successful.

Technical and operational evaluations will be performed on USS NORTON SOUND (AVM-1) in late 1981 and early 1982 with the installed Aegis Weapon System and SM-2 Block I missiles.

During the validation phase of VLS, it was demonstrated that it was feasible to vertically launch Standard missile (SM-1) from conventional and high speed surface ships, to fabricate lightweight canisters for storing and launching SM-1 and to fabricate a Gas Management System (GMS) capable of safely containing and venting the exhaust of SM for a normal launch or in an inadvertent restrained firing. A five-cell baseline PPM was used to validate the GMS.

STANDARD MISSILE - VERTICAL LAUNCHING SYSTEM, EMERGENCE DYNAMICS

The dynamics of a missile being launched from the nontrainable Vertical Launching System (VLS), and consequently its initial heading, is influenced by many mechanical and gas dynamic interactions from the launching system. An analytical study to evaluate this problem (in the form of a six degree-of-freedom computer simulation) was initiated by the Martin Marietta Corporation (MMC), the prime contractor for full-scale development of the VLS. The JHU/APL was given the task by NAVSEA to review this program. The MMC program was converted to run on the JHU/APL IBM 3033 computer. The JHU/APL, with assistance from the MMC, has validated the MMC program after some modification. Analytic results from the program show that a physically meaningful representation of egress of the SM-2 Block I missile from the VLS canister is obtained. The program is now a useful tool for verifying the integrity of VLS structural components (or for identification of potential hardware modifications) and for determining initial missile heading and rates for a missile launched from a vertical canister.

DISCUSSION OF PROGRESS

Validation by JHU/APL of the MMC VLS SM-2 Block I flyout simulation has been completed. Analytical results show that the program provides a physically meaningful representation of egress of the SM-2 Block I missile from the VLS canister. It is now a useful tool for verifying the integrity of VLS structural components (or for identification of potential hardware modifications) and for determining initial missile heading and rates for a missile launched from a vertical canister.

Preliminary predictions with the MMC simulation indicated that unacceptably high forces on the launching shoes and folded fins were generated during launch in a shipboard tactical launch environment. The impact of these results on possible hardware redesign led to an in-depth review by JHU/APL of the MMC flyout simulation.

During the past year, JHU/APL with the assistance of MMC identified errors in the original program which had produced erroneous values of fin forces. The program was modified and the present results indicate that it is no longer necessary to consider redesign of the fin restraint rail to reduce fin forces.

On shoe forces, the results of the updated program suggest that shoe forces are being calculated correctly. However, because of the sensitivity of these forces to analytic modeling of the spring constants for the shoe guide rail system and the shoe-guide rail geometry, and to the moment of inertia, experimental verification of these input parameters should be obtained prior to hardware modification.

HUGHES AIRCRAFT COMPANY
MISSILE SYSTEMS GROUP

R.M. Rogers

LAUNCH TRANSIENT ANALYSIS AS PERFORMED AT HUGHES AIRCRAFT COMPANY

The Missile Systems Group method for conducting launch transient analyses is based on the grid force and moment technique. Data generation is accomplished using a CTS rig to automatically traverse the store model through a grid volume in the vicinity of the aircraft carriage position and likely trajectory paths. Aerodynamic forces and moments are measured on the store at discrete points within the interference flow field, and are then reduced to yield a matrix of perturbation terms representing the aircraft interference flow field. This matrix is then used in conjunction with a high order of 6-DOF trajectory simulation program to simulate the launch transient phenomena.

Due to the ever increasing cost of wind-tunnel testing, the Missile Systems Group has begun investigating means of supplementing experimental aircraft interference flow field information with analytically generated data. The primary focus to date has been on the Nielsen Store Separation Trajectory Program. Current efforts include expanding the aircraft mathematical library. A model for the Hawker Hunter has been created and efforts are underway to develop an F-111 model.

MCDONNELL AIRCRAFT COMPANY

P.L. Pondrom

1981 STORE SEPARATION ACTIVITIES

McDonnell Aircraft Company is conducting store separation analysis and flight test demonstration for the F-18 Hornet, AV-8B Harrier, and F-15 Eagle. This report contains a brief summary of work related to launch dynamics for each project.

F/A-18 HORNET

Flight testing during FY-81 has demonstrated several store separation and jettison envelopes for the F/A-18 aircraft. Launch envelopes for the AIM-7F Sparrow missile from the fuselage and the AIM-9L Sidewinder missile from the wingtip have been established. Flight demonstration testing has also established separation envelopes for the MK-82 SE and MK-83 LD bombs deployed from the centerline and inboard wing pylons, as well as a jettison envelope for the 315-gallon fuel tank from the centerline pylon. A significant amount of testing has been accomplished on the following stores from the centerline and inboard wing stations: MK-76, BDU-12, external fuel tank, Walleye Data Link Pod, bomb rack, and bomb rack-store combination. Flight test demonstration of store separation capability from the outboard wing station is in progress. In addition to the flight test program, a wind-tunnel test was conducted at Arnold Engineering Development Center (AEDC) in support of the flight test program.

Both the Sidewinder and Sparrow missiles have been launched successfully throughout the aircraft's air-to-air missile deployment envelope. The flight testing of the F/A-18's basic air-to-air loading (Sidewinders on the wingtips and Sparrows on the fuselage) is essentially complete. This includes jettison testing of the fuselage mounted Sparrow missiles. Demonstration testing of missile launch capability from the outboard wing pylon (two Sidewinders or one Sparrow) is currently underway. The missile jettison testing from this wing station consists of missile/rail launcher combinations.

For the air-to-ground weapons, the store separation characteristics from the F/A-18's centerline and inboard pylons have proven satisfactory. The combination of a nosedown aerodynamic pitching moment and the high end-of-stroke velocity of the vertical ejector rack (VER) has produced clean separations from the aircraft throughout the air-to-ground deployment envelope. It should be noted that even without ejector force, the low-mass MK-76 practice bomb has exhibited successful separation from all six stations of a multiple ejection rack (MER), while carried on the inboard pylon up to speeds of 500 knots. Initial flight test results for separation from the outboard wing pylon also show favorable weapon separation characteristics.

The flight test demonstration of the F/A-18's jettison capability of external fuel tanks, Walleye Data Link Pods, and VER-store combinations has proven to be as successful as the air-to-ground separations. The only flight test anomaly to date involved a VER jettisoned from the inboard wing pylon, which did not exhibit the nosedown motion predicted by the wind-tunnel drop test. Because no grid survey data exist for the VER, jettisoning of the VER has been curtailed until additional wind-tunnel data are available.

To support the flight test program, the sixth in a series of store separation wind-tunnel tests was conducted at AEDC in August of 1981. The stores tested were VER's, LAU-61 (rocket launcher), and the VER-LAU-61 combination. In addition to captive trajectory system (CTS) and grid survey data, freedrop test data were obtained for the VER and VER-LAU-61. The previous freedrop testing used heavy-scaled wind-tunnel models. It should be noted that in drop model testing either the heavy-scaling mass properties (affecting the vertical displacement) or the light-scaling moments of inertial properties (affecting the angular displacement) can be modeled. Because the moments of inertia properties were shown to be more dominant, based on the VER flight experience discussed above, light-scaled drop models were used. A comparison of trajectories from light and heavy scaled models will be made when data are released from the AEDC.

In order to compare drop model test time histories to the grid survey database, a computer program has been developed which extracts the aerodynamic coefficients from the drop test camera results. The computer code used to extract force and moment coefficients from separation time histories can operate on wind-tunnel or flight test photometric results. The photometric results consist of a time history of the store displacements. The store acceleration is derived from the second order derivative of this displacement time history. Because errors will easily propagate in the derivative-calculation process, precise reading of the high speed film records (at sufficient intervals) is essential for accurate determination of aerodynamic coefficients. In addition to the extracted total coefficients, the code can obtain an increment between the flight test results and a wind-tunnel database. This option will permit quick comparison of flight and wind-tunnel results for any flight condition.

AV-8B HARRIER

Flight test demonstration of AV-8B store separation capability will begin the end of October at NATC, Patuxent River. The test plan consists of approximately 60 flights. The stores to be tested include air-to-ground bombs (MK-81 LDGP, MK-82 SE, MK-83 LDGP), MK-76 and MK-106 practice bombs, LAU-10 rocket launchers, triple ejector racks (various loadings), and the 300-gallon external fuel tanks.

In support of this flight test effort, a program composed of three series of store separation wind-tunnel tests were completed during 1980 and 1981 at AEDC. A total of 4291 runs were made during this test program (1437 CTS, 2812 grid surveys, and 42 free drops). The stores evaluated were air-to-ground bombs (MK-81, MK-82 LDGP, MK-82 SE, MK-83 LDGP), the MK-36 LD destructor, BL-755 and MK-20 Rockeye II cluster bombs, AGM-65 Maverick missile, LAU-10 rocket launcher, and the 300-gallon external fuel tank. The fuel tank investigation included six fuel loadings of two defueling sequences, three tank fin configurations, and two sets of ejection forces.

The wind-tunnel data acquired during these tests are used as the database for a six degree-of-freedom store separation program. This computer code has been developed by modifying the F/A-18 program to match AV-8B hardware. The trajectory simulation program has been correlated with the wind-tunnel CTS results and will be used to support the flight test program.

F-15 EAGLE

The safe launch of the Sparrow missile from an F-15 configured with conformal fuel tanks has been demonstrated. In addition, computer studies of the AMRAAM missile launched and jettisoned from the Eagle have been performed on the prototype missiles of both the Raytheon Company and the Hughes Aircraft Company. An additional computer study was performed for the carriage and deployment of an advanced design "special purpose" missile (PMALS) from the centerline of the F-15 aircraft.

Sparrow missile separation capability from an F-15 with conformal fuel tanks was documented in a test program conducted for the Israeli Air Force. The test program demonstrated the launch and jettison envelope of the AIM-7F missile separating from the fuselage corner of the F-15 aircraft configured with conformal fuel tanks. The tests were conducted at Edwards Air Force Base, California during the time period of December 1980 through January 1981. The flight test results certify a large launch envelope for the Sparrow missile in the presence of the conformal fuel tanks.

The six degree-of-freedom program used in the analysis of the Sparrow missile launch and jettison capability was modified for use in the Advanced Medium Range Air-to-Air Missile (AMRAAM) studies. These studies investigated the separation and jettison characteristics of the AMRAAM prototype from the F-15 aircraft. The AMRAAM missile can be launched by a fuselage mounted ejector system or by a rail launch system from the wind pylons. Launch simulations were performed at several flight conditions including those to be used during the AMRAAM validation phase flight test program.

Similar analytic studies were performed on the PMALS missile launched from the centerline pylon of the F-15 aircraft. During the missile launch, the parent aircraft is performing a roll maneuver in order to provide additional separation distance. The study includes missile and aircraft flow field effects, missile plume effects, umbilical effects, ejector dynamics, and missile control during separation.

NORTHROP VENTURA DIVISION

A.J. McEwan

Northrop Ventura Division (NVD) is a developer and manufacturer of unmanned vehicle systems for target and tactical applications. A significant part of NVD's engineering work normally falls within the purview of the Launch Dynamics Panel. However, during the past year the engineering effort has been concentrated in vehicle definition on three new systems and, consequently, unusually little in the way of launch dynamics progress and problems has been experienced. As these new systems move along the development path in the next few years, there will be a heavy emphasis on launch dynamics concerns.

BWM-74C

As reported last year, the BQM-74C air launch and surface launch analyses and initial testing were completed without problems. During the past year development testing was completed and the system became operative, including use in Mobile Sea Range operations. Launch continued to be successfully demonstrated. A paper titled "BQM-74C Air Launch Qualification" was presented by A.J. McEwan at the Association of Unmanned Vehicle Systems 1981 Annual Meeting in Washington, D.C. Engineering effort was started on the integration of Northrop Chukar II tow systems into the BQM-74C design.

MQM-74C/CHUKAR II

Problems have been encountered with the separation of the new NR-4113 jatos from the Chukar II. The jato separation trajectory occasionally results in the jato impacting the carrying away the tail, which necessitates mission termination. The NR-4113, relative to the jato it replaces, has more impulse (and, therefore, a higher end speed), a lower ballistic coefficient W/C_DS and, because of a longer burn time, causes the vehicle angle of attack to be lower at jato separation. A definitive separation analysis conducted in 1973 on an earlier version of the system indicated that mechanical friction in the separation system and low values of vehicle angle of attack were the two parameters which caused the greatest degradation in separation system performance. That analysis also showed that higher end speed and lower jato ballistic coefficient were significant, but secondary, parameters degrading separation clearances. Hardware recovered after failures of the NR-4113 to successfully separate, indicated that the NR-4113 showed more susceptibility to friction and bindings than its predecessor. Thus, all four parameters cited were less favorable for the NR-4113 than for its predecessor, which exhibited reliable separation characteristics. Further investigation showed that the lubricant used in the NR-4113 actually worsened the friction effects due to flaking and accumulation, and a superior substitute was chosen. A hardware modification was made to greatly reduce mechanical binding and a change was made in the commanded pitch angle during launch which results in a higher vehicle angle of attack during separation. These modifications have resulted in reliable separation of the NR-4113. This outcome demonstrates the values of the definitive separation analysis from 1973, which identified the critical parameters affecting separation performance, which saved NVD from expending effort on noncritical parameters at the time of the NR-4113 failure investigation.

NVD is currently planning the development of "nose tow" capability. Presently all deployable tows are of the "c.g. tow" type. Progress and problems experienced will be reported on next year.

BQM-PI

The NVD is starting a detailed design of the BQM-PI, a low-cost Mach 0.9 Navy target for which the RFP is expected soon. Problems that will be solved as part of that effort include surface launch, jato separation, air carriage and launch from a large number of Navy aircraft (including carrier-based aircraft), carriage of fixed and deployable stores on underwing pylons, separation and tow of stores, and vehicle recovery by parachute. These efforts will be reported on next year.

SANDIA NATIONAL LABORATORIES

H.R. Spahr

THEORETICAL STORE SEPARATION ANALYSES

The Sandia version of the AFFDL/NEAR subsonic theoretical store separation computer program contains modifications made to the program by AFFDL, NEAR, NWC, and Sandia to extend its capabilities. During the past year, no new modifications have been added to the program.

Higher priority work has prevented finishing the F-111A wing mathematical model needed to complete a mathematical model of the F-111A aircraft for use with the AFFDL/NEAR program. Work on the F-111A model will be continued during this next year.

Theoretical analyses were completed for the Advanced Tactical Bomb (ATB) prototype store. These analyses were conducted to obtain permission to conduct full-scale flight drop tests using NWEF A-7 aircraft.

The ATB is 18 in. in diameter, 145 in. long, and weighs 1,600 lb. This prototype store has four fins with a 32.8 in. diagonal fin box dimension.

The aerodynamic characteristics of the ATB were computed over the Mach number range of interest using the NSWC computer code. These calculations showed the ATB has an aerodynamic static margin of, approximately, 12 percent (of body length).

Sandia had previously dropped a number of prototype stores which were similar in geometry and mass properties to the ATB. Also, these prototype stores had static margins which bounded the ATB static margin. Therefore, detailed store separation calculations (using the AFFDL/NEAR computer program) were not needed.

RACK EJECTION TESTS (USING NEW CCU CARTRIDGES)

The Air Force has conducted 50 MAU-12 rack ejection tests of Ballistic Drop Units which simulate the mass and inertias of the B43, B57, and B61. These tests used the new CCU-43B cartridges and the old ARD-446 and ARD-863 cartridges which are being replaced. The rack orifices tested are those used on F-4 and F-16 aircraft. Results from these tests will define the acceptability of the new cartridges as replacements for the old cartridge.

Computer program EJECT, written at Sandia, uses as input data digitized vertical displacement and angular position data from high speed motion picture coverage of rack ejection tests of stores. The program determines the ejection velocity and ejection angular rate for the store.

Computer code EJECT is currently being used by Sandia to reduce data from motion picture coverage of these rack ejection tests. The ejection velocity from the Sandia data reduction will provide an independent value for comparison with the ejection velocity from the Air Force break wire instrumentation. The Sandia data reduction is the only source of ejection angular rate data.

FULL-SCALE FLIGHT DROP TESTS

Full-scale flight drop tests of two new Sandia stores were conducted in the past year. These tests are summarized briefly below.

The flight drop test development program for the B83 store is continuing. (The B83 is a simpler, lower-cost version of the B77 store.) This store is 18 in. in diameter, 144 in. long, and weighs 2,400 lb. Each store has four fins with a 31.8-in. diagonal fin box dimension. The B83 has a static margin of approximately 20 percent. B-52, F-4, and F-111 aircraft are being used in the drop test program.

The flight drop test development program for the Advanced Tactical Bomb (ATB) was started this past year. The NWEF A-7 aircraft is being used in the drop test program.

No store separation problems were encountered during these full-scale flight drop tests of B83 and ATB stores.

ACTIVITIES PLANNED FOR NEXT YEAR

Development of the F-111A theoretical aircraft model for use with the AFFDL/NEAR subsonic store separation computer program will continue.

In the next year, Sandia will get a CRAY-1 computer. Therefore, the AFFDL/NEAR program will be rewritten to take maximum advantage of the vector processing capabilities of the CRAY.

Rack ejection tests will be completed for Sandia stores ejected from the F-104 rack using the new CCU cartridges. Computer program EJECT will be used to reduce the data from this series of tests.

Ejection tests of a B61 instrumented store from a MAU-12 rack will be conducted. The instrumented store has accelerometers to define the response of certain internal components to the ejection forces. The results of these tests will be used to define the ejection environment that any new components must survive.

Full-scale flight drop tests will be conducted for new versions of the B28 and B61 stores. The new versions of these stores will have external shapes virtually identical to the old versions. Mass properties of the new version of these stores will be close to those of the old versions. The B-52 aircraft will be used for the B28 drop tests and B-52, F-4, and F-111 aircraft will be used for the B61 drop tests.

VOUGHT CORPORATION

F.W. Prilliman

ASSAULT BREAKER

Vought is currently in the flight test phase of a demonstration contract with the Army Missile Command involving development of a submissile or submunition dispenser and the T-22 missile delivery system. The overall program is under the sponsorship of the Defense Advanced Research Projects Agency (DARPA). The current phase involves a six flight demonstration test program. Martin Corporation holds a similar contract with DARPA with the major difference being that Martin uses a 16-in. diameter Patriot missile as the delivery vehicle, whereas Vought is using a 22-in. diameter vehicle which is a SIG-D missile derivative. The baseline missile system is intended to demonstrate technology capable of accurate, multiple, subweapon delivery exceeding currently deployed Lance system range, payload, and delivery capabilities.

A terminally guided submissile (TGSM) and a skeet delivery vehicle assembly (SDVA), submissiles and submunitions, respectively, were dispensed during the tests from the exposed forebody dispenser bays. A significant test result has been the verification that subweapon separation is quite similar to preflight estimates predicted using analytical techniques. This includes some occurrences of subweapon tumbling at eject which were predicted via the combined modeling of flight condition, local flow interference, ejector mechanism, and subweapon aerodynamic effects. Substantial prior supersonic wind-tunnel airload and separation testing, specialized trajectory routine development, and ejector mechanism testing including sled qualification tests were instrumental in the separation prediction efforts. During both flight tests, subweapon laydown was achieved in the prescribed patterns and distribution.

LAUNCH DYNAMICS PANEL RECOMMENDATIONS TO NAC

Three recommendations were generated by the panel during the meeting.

1. RECOMMENDATION:

Experimental flow-field data of service aircraft should be measured for use in the validation of the mathematical models used in the analytical methods currently being used for computing store carriage loads and store separation predictions. Also measure air loads on the store.

BACKGROUND:

Analytical methods are increasingly being used in the prediction of store-carriage loads and store-separation predictions to reduce the need for expansive and extensive full-scale flight tests and wind-tunnel tests. These analytical methods use a mathematical model to represent the aircraft in the calculation of flow field interaction between aircraft and store. At present many or most of the aircraft mathematical models used have not been checked for accuracy due to the lack of the experimental flow field data required for validation. Due to the increasing use of aircraft mathematical models in these and other aerodynamic prediction methods, the need for data to be used in the validation of the aircraft mathematical models is becoming more and more important.

2. RECOMMENDATION:

Support studies in the determination of local flow influence coefficients from experimental data of one store for use in estimating the influence coefficients for another similar store.

BACKGROUND:

Extensive experimental data files exist of store and aircraft captive trajectory wind-tunnel store separation tests of many current stores and aircraft. Methods have been investigated which show promise in the estimation of local flow field influence coefficients from data for one store that may be used in the estimation of the influence coefficients for a second store. Further development of these methods may provide a means of using an existing databank for determining influence coefficients for a future store shape. This would extend the usefulness of the existing coefficient databank and decrease the need for extensive tests of new stores in the wind-tunnel captive trajectory systems.

3. RECOMMENDATION:

Support effort to retain the captive trajectory system (CTS) capability at DTNSRDC through reprogramming and provision of the necessary interface hardware to a new computer system.

BACKGROUND:

The present CTS system at DTNSRDC was developed and initially operated in the early 1970's. The system has remained basically unchanged since that time with some recent remodelling of the electronic control system and is in excellent mechanical condition. The computer equipment at DTNSRDC is being replaced and a conversion of the interfacing hardware and software is necessary to keep the CTS system operational and efficient. The DTNSRDC system is the only Navy CTS system available and is one of only two such operational systems in the U.S.; the other being at AEDC, Tullahoma. The current trend for increased wind-tunnel tests and analytical store prediction separation predictions to replace expensive and extensive full-scale flight testing of hardware has increased the need for CTS facilities. The conversion to the new computer equipment will provide an opportunity to incorporate many changes based on experience gained with the present system as well as allowing the use of a faster, more reliable computer.

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1981 REPORT TO THE

NAVY AEROBALLISTICS COMMITTEE

FROM THE

MISSILE STABILITY AND PERFORMANCE

PANEL

INTRODUCTION

The panel met at the David W. Taylor Naval Ship Research and Development Center on 5-7 October 1981. Members present reported on accomplishments in their respective activities during the past year and formulated technical recommendations for consideration by the NAC. These are reported here.

The attendees were:

Mr. Gene Aiello	Martin Marietta Aerospace Orlando Division
Mr. Jerry Allen	NASA Langley Research Center
Mr. Roy Anderson	Naval Air Development Center
Mr. M. Michael Briggs	Nielsen Engineering and Research, Inc.
Mr. Steve Carter	Naval Weapons Center
Mr. D.P. Forsmo	Raytheon Co.
Dr. Michael J. Hemsch	Nielsen Engineering and Research, Inc.
Mr. K.A. Larsen	Pacific Missile Test Center
Dr. Alan R. Mitchell	The Analytical Sciences Corp.
Dr. T.R. Pepitone (Chairman)	Naval Surface Weapons Center
Mr. Mark A. Pinney	Wright Patterson Air Force Base
Dr. C.F. Price	The Analytical Sciences, Corp.
Mr. F.W. Prilliman	Vought Corp.
Mr. G.D. Stilley	Honeywell, Inc.
Mr. R.M. Taylor	David W. Taylor Naval Ship Research and Development Center
Mr. L.E. Tisserand	Johns Hopkins University Applied Physics Laboratory
Dr. D.J. Trulin	General Dynamics, Pomona

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

R.M. Taylor

TINKERTOY

Since 1978 DTNSRDC and NASA Langley Research Center have supported the Naval Weapons Center, China Lake, in a parametric investigation of airbreathing missile aerodynamics. Each year the database has been broadened, with DTNSRDC performing transonic experiments and NASA Langley performing the supersonic experiments.

During the past year an attempt was made to fill some of the gaps in the control effectiveness data matrix. One result of the transonic investigation is that with the missile yawed 5 deg nose left and at angles of attack above 17.5 deg the sign of the side force changes from negative to positive. This appears to be due to the asymmetric shedding of vortices on the nose and forebody of the missile. A report on this effort is in preparation at this time.

NAVAL AIR DEVELOPMENT CENTER

R. Anderson

TECHNICAL EVALUATION OF THE BQM-74C TARGET DRONE

In May 1981, the U.S. Navy completed a technical evaluation of the Northrop BQM-74C target drone. The BQM-74C is a high midwing monoplane of conventional design with an inverted "Y" empennage, developed to provide subsonic threat simulation for U.S. Navy weapon systems training and evaluation. The target can be land, ship, or air launched and can be used for land based, shipboard, or air-to-air target missions. Launch adapters were developed at the Naval Air Development Center (NAVAIRDEVCEN) to allow air launch from the A-4 and A-6 aircraft. Also, separation studies and structural analyses were conducted at NAVAIRDEVCEN for flight certification prior to air launched flight tests at the Naval Air Test Center, Patuxent and the Pacific Missile Test Center, Point Mugu.

Of significance is the fact that the BQM-74C is the first U.S. Navy aerial target to incorporate a fully digital avionics processor (DAP). The digital processor provides mission flexibility through the use of a variety of different avionics configurations. The BQM-74C has three major avionics suites, those being: (1) the basic configuration which allows remote control of the target via an ultra-high frequency (UHF) command and control link, (2) the mobile sea range (MSR) configuration which incorporates preprogrammed mission flight profiles with a limited UHF remote command override capability, and (3) the on-range target (ORT) configuration which combines the capabilities of the basic configuration with various combinations of MSR subkits. The ORT configuration uses the integrated target control system (ITCS) for target command and control instead of an UHF command link.

Technical evaluations of all three configurations have been completed; the latest evaluation being of the MSR configuration which flew a 250-mile preprogrammed mission, simulating a long-range cruise missile. Operational evaluation of the BQM-74C is scheduled for the near future.

PERFORMANCE IMPROVEMENT OF THE AQM-37A MISSILE TARGET

In June 1981, the U.S. Navy also completed an evaluation of a modified Beech AQM-37A guided missile target called the Variant. The AQM-37A is a liquid-rocket-propelled, air-launched, supersonic, nonrecoverable guided missile target used for air defense missions and manned aircraft training operations. Its basic performance envelope extends from 100 feet up to 70,000 feet and from Mach 0.6 to Mach 2.0.

The AQM-73A Variant is a basic AQM-73A which has been modified to include some minor autopilot gain changes, improved static pressure sensing, high-temperature bonding and larger vertical stabilizers for improved lateral-directional stability. These modifications allow the Variant to expand its basic performance envelope to include flight at Mach 3.0 at 80,000 feet. Under contract to the U.S. Navy, Beech Aircraft Corporation conducted a flight test program demonstrating the improved flight performance of the Variant. That program was successfully concluded in June 1981. In the near future the Navy will evaluate an AQM-37SP which is a further modified Variant with a terminal dive capability, preselectable dive angles, commanded course correction capability, and an improved digital avionics processor.

NAVAL WEAPONS CENTER

AIRBREATHING MISSILE AERODYNAMIC STUDIES

The Airbreathing Missile Aerodynamics Program is a continuing effort at NWC with the following general goals: develop theoretical and empirical aerodynamic prediction methods applicable to airbreathing missile configurations, investigate inlet effect on missile aerodynamics and develop an experimental and analytical aerodynamic technology database, and evaluate the stability and control characteristics and requirements of airbreathing missile configurations when operated in a bank to turn steering mode.

The Tinkertoy testing was completed. Reports by NASA Langley and DTNSRDC are in preparation. The stability and control study final report was completed. Nielsen Engineering and Research (NEAR), Inc. has completed a handbook of data on inlet contributions to external missile aerodynamic characteristics. The data will be presented in a uniform format and with consistant definition of variables. NEAR, Inc. will prepare a supplement to include the remainder of the Tinkertoy data.

ADVANCED COMMON INTERCEPT MISSILE DEMONSTRATION PROGRAM (ACIMD)

The ACIMD program is a new start for FY-81. The general goals of this program are to design, build, and flight test a ramjet powered air-to-air missile. The principle objectives for the aerodynamics portion of the program are to: define the preliminary drag and lift based on prior Airbreathing Missile studies, use the propulsion system determined from the preliminary studies to determine an external configuration and aerodynamics of this configuration, and use wind-tunnel results and predictions to document the aerodynamics of the final configuration in preparation for a flight test program.

Using data collected from the Tinkertoy, LFRED, tail control Sparrow, and other wind-tunnel tests, a database system was defined for this class of missile, and preliminary aerodynamics for the desired configuration were determined. From this baseline aerodynamic data, it was determined that a DRED type inlet would be required to meet the range, altitude, and Mach number goals.

The Tinkertoy model was adapted for use in the wind-tunnel test program. Preliminary supersonic tests are scheduled to start in October and subsonic-transonic testing in November 1981.

Currently, this concept appears to be feasible, but many minor problems still need to be solved before flight testing of a flight vehicle can be accomplished.

NAVAL SURFACE WEAPONS CENTER (NSWC)

HYPERSONIC WIDE AREA DEFENSE MISSILE, AERODYNAMIC TRADE STUDY

A trade study of aerodynamic configurations for an airbreathing hypersonic wide area defense missile (HWADM) is being conducted at NSWC under the sponsorship of the Naval Sea Systems Command's Aerodynamics and Structures Block. This work is being coordinated with APL who is performing structural design studies of these configurations and hypersonic wind-tunnel data correlations. The baseline external shape is that of an existing HWADM concept, having a 21-inch diameter cylindrical body with an annular inlet, wing islands, and tail control surfaces. Modifications to the baseline may include a lengthened and slimmed body, thin dorsal fins, nonaxisymmetric shaping of the body, and a chin inlet. Aerodynamic coefficients are being estimated using the NSWC SWINT code and variations of the Air Force HABP. Computed results will eventually be compared with the results of the wind-tunnel data correlations.

The primary performance objective is an extended powered range. Later effort may concentrate on the improvement of maneuverability and terminal homing responsiveness. The hypersonic aerodynamics and structures work will eventually be coordinated with the results of other disciplinary studies concerning hypersonic wide area defense missiles to define configuration options for wind-tunnel tests.

ADVANCED COMMON INTERCEPT MISSILE

The advanced common intercept missile (ACIM) task, currently in progress, includes a performance comparison between the surface unique solid rocket design and the integral rocket ramjet or droppable booster design. One of the major goals of this effort is to determine the ability of both ACIM and the surface unique variant to engage high speed sea skimming threats at minimum range. Intercepts at this range require very short times-of-flight which may not allow sufficient time for staging and ramjet ignition of the airbreathing design. Also, ACIM may be incapable of providing the maneuverability levels required by such an engagement.

Current propulsion, aerodynamics, and other configuration data relevant to the current definition of ACIM are being obtained from NWC and other contractor sources and incorporated into existing dynamic simulations of the ACIM. Preliminary data pertaining to the TVC separable booster are currently in hand. Aerodynamics will be based on the modified LFRED database. Integral rocket ramjet performance is also being obtained from NWC and Marquardt.

In FY-82 flight control policies will be developed for the TVC boost, IRR boost, and ram jet sustain phases of flight. Kinematic performance boundaries, based on the aforementioned aerodynamics and propulsion data, will be generated for the APODS and MSAMS missions. If an effective midcourse guidance policy encompassing considerations of efficient energy management and main lobe jamming becomes available in the course of the study, these performance boundaries will be refined to reflect a more realistic tactical environment.

Six degree-of-freedom simulations of engagements of the APODS/MSAMS target spectrum will be performed to further assess kill achievability.

Should be ACIM configuration, as presently defined, as bound to be incompatible or inadequate in meeting APODS/MSAMS mission requirements, further design work is planned.

ADVANCED AERODYNAMIC CONTROL CONCEPT

The NSWC is currently addressing the problem of development and demonstration of modern control techniques in the design of high performance, airbreathing, air-to-air missile configurations. The work is designed to bring the modern control concepts already demonstrated closer to a practical autopilot design, evaluated in a more realistic environment.

Previous work reported under this task has shown that state variable feedback methods are a very effective means of implementing flight control during terminal homing. The optimal state tracking algorithm developed under this project has been very successful in affecting bank-to-turn control of a twin axially symmetric inlet air-to-air missile configuration over a wide range of supersonic flight conditions during closed-loop terminal homing. In addition, the control scheme has exhibited a considerable degree of insensitivity to assumed modeling errors associated with the linearized aerodynamics used in the controller development. However, these schemes must rely on reasonably accurate measurements of the missile state (angle of attack, sideslip, etc.). Airframe angular rate information will probably be available through the use of strapdown body rate sensors or inertial reference units as should also be a reasonable measurement of bank angle. However, angles of attack and sideslip, necessary for maneuver and sideslip regulation, are not directly measurable and must be inferred or estimated from available instrumentation.

Several approaches to the real-time estimation problem are being investigated, ranging in complexity from classical filter networks and deterministic observers to stochastic methods such as Kalman estimation techniques. At least two of the most promising techniques representing a range of sophistication and complexity will be evaluated via closed-loop homing six-degree-of-freedom simulations in conjunction with previously developed flight control systems. Estimation and data processing delays will be introduced to simulate, as closely as possible, a realistic flight environment. Rate gyro and accelerometer response and noise characteristics will also be included to evaluate the degradation in missile response and controllability.

The effects of elastic body coupling will be included in the flight control system development and incorporated into the flight simulation. Longitudinal and lateral vibration mode shapes and frequencies will be obtained on a contemporary airbreathing missile configuration (ACIM). Strapdown sensor placement will conform to realistic constraints of the airframe design. The linear optimal state tracking flight control algorithm, incorporating compensation for the assumed vehicle aeroelastic response will be evaluated via six-degree-of-freedom closed-loop homing simulations against selected targets. Sensitivity to uncertainties in assumed vehicle aeroelastic response characteristics are also being determined.

JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY

STANDARD MISSILE TYPE 2, EXTENDED RANGE, BLOCK II PROGRAM

Future improvements to the SM-2 missile, capable of higher speeds to counter the advanced-missile threats to the fleet, are being investigated in the SM-2 ER, Block II Program. The improved version will be required to operate at higher altitudes and at considerably greater speeds than the SM-2 missile. Upgraded booster propulsion will be used to achieve these objectives. Some intercepts at higher altitudes will require the large-gee maneuvers associated with large angles of attack.

In support of this missile improvement program, extensive wind-tunnel testing was carried out successfully by APL at the Arnold Engineering Development Center. This testing was the first experimental investigation into the three-dimensional aerodynamic force and moment characteristics that act on this class of configurations in the high Mach number, large angle of attack regimes. The test results obtained have been analyzed, on a priority basis, to provide aerodynamic information needed for the design of the airframe. This effort included the derivation of a complete three-dimensional, nonlinear, aerodynamic description of the missile that provides the inputs needed to support valid computerized, six-degree-of-freedom, trajectory simulations and dynamic-flight investigations. The full missile simulation is operational and is being used extensively in the on-going design and performance evaluations of the SM-2 ER, Block II missile.

A major milestone was reached in November 1980 with the successful completion of the first phase of the flight test program. This program, consisting of four flights, took place within a twelve-month period. The highly instrumented flights provided information in the extended speed and altitude ranges. APL evaluations of flight data and simulation output show that the propulsion, aerodynamics, and controllability have been validated, and that the Development Program can advance to the guidance test phase with confidence that the airframe will perform kinematically as predicted.

STANDARD MISSILE 1, MEDIUM RANGE, UPGRADE AND STANDARD MISSILE TYPE 2, MEDIUM RANGE, BLOCK II PROGRAMS

The SM-1 MR, Upgrade and SM-2 MR, Block II airframes have the same external geometry. Improvements to these weapons include an upgraded propulsion system that will provide for higher-speed, higher-altitude intercept capabilities.

Early APL analyses associated with stability and control characteristics, referred to the airframe's new mass properties, showed that configurational candidates having the long SM-1 MR-type dorsal fins would exhibit excessive longitudinal stability during the coast portion of flight. Follow-on analytic studies indicated that a shorter length dorsal would reduce the airframe's stability margin, improve maneuverability, and still be compatible with proposed launchers. Wind-tunnel tests confirmed these aerodynamic predictions and provided definitive information for the judicious selection of a tailored dorsal-fin planform. The resulting configuration, with the shorter dorsals and an elongated body, was then subjected to extensive wind-tunnel testing to obtain the experimental data needed for the determination of the airframe's three-dimensional aerodynamic lift, stability, control, and tail hinge-moment characteristics appropriate to the vehicle's subsonic, transonic, and supersonic flight regimes.

In the past year, a full three-dimensional description of the aerodynamic forces and moments that act on the missile in three-dimensional maneuvering, from launch to intercept, was completed. The description is based on the tunnel data and provides the nontrim, highly nonlinear aerodynamics. Its incorporation in computerized dynamic-flight simulations that have six degrees of freedom will provide the Navy with a powerful analytical tool for evaluating the weapon system design and performance.

AERODYNAMIC STUDY OF HYPERSONIC RAMJET MISSILE CONFIGURATIONS

Hypersonic ramjet missiles have been proposed by APL as a means of countering advanced threats to the fleet. One conceptual design is a nose-inlet ramjet designed for hypersonic operation. The Navy has given support to APL for propulsion development, including inlet and combustor tests, and for missile performance evaluation studies.

External aerodynamics for the different configurational candidates are being estimated analytically. Because experimental data pertinent to the airframe development are very sparse, a wind-tunnel test program has been proposed to investigate the aerodynamics for a class of nose-inlet, hypersonic ramjet configurations. The results would be valuable in accessing and optimizing the airframe's lifting, stabilizing, and control characteristics. Investigations addressing the integration of tunnel characteristics and balance capabilities with model design, and the selection of test configurations have been reported.

A simple, empirical method has been developed at APL for predicting, at high speeds, the lifting force on very-low-aspect-ratio wings mounted on bodies of revolution. Results obtained using this method are in good agreement with experiment for angles of attack up to 24 deg for Mach numbers 2.5 to 7.7.

An engineering method has been developed at APL for calculating, at high-supersonic speeds, the effects of blunting the leading edges of lifting surfaces. For the blunting radii expected on tactical-missile surfaces in the Mach range 3 to 8, it was determined that the effects on normal force and center of pressure can be expected to be minor, whereas the effects on drag can be expected to be significant.

BANK-TO-TURN CONTROL TECHNOLOGY FOR HOMING MISSILES

The APL has conducted recent investigations into the bank-to-turn (BTT) steering concept. The well advertised benefits associated with BTT steering are that maneuverability and aerodynamic controllability can be enhanced when maneuvers are executed in a preferred aerodynamic roll attitude, which for airbreathing missiles can be the roll attitude which provides the best environment for air-inlet performance. The objective of the APL investigations was to go beyond the kinematic analyses and focus attention on the BTT-guidance techniques and autopilot-design criteria that are needed for the successful implementation of a BTT-control system.

Initial results prompted the NASA Langley Research Center to fund APL to prepare a "Bank-to-Turn Control Technology Survey for Homing Missiles." This report summarizes the advantages of BTT steering, reviews the recent and current programs that are actively investigating or considering BTT steering, and assesses the status of the critical technology areas associated with BTT control. A follow-on investigation has produced, in the past year, a "Homing Performance Comparison of Selected Airframe Configurations Using Skid-to-Turn and Bank-to-Turn Steering Policies" (NASA CR 3420). This investigation included homing-flight and intercept-performance (miss distance) comparisons against maneuvering targets between bank-to-turn and skid-to-turn policies applied to interceptors having both high-lift and moderate-lift airframes. Two representative missions were examined: a medium-range, area-defense mission and a longer range, raid-suppression mission. Results indicate that bank-to-turn steering can provide acceptable performance provided that moderately high bank rates can be tolerated.

The consequences of the body-motion coupling on the autopilot design are being evaluated in the next phase of the investigation.

VOUGHT CORPORATION

F.W. Prilliman

SUPERSONIC TACTICAL MISSILE (STM)

Vought is under contract to the Naval Weapons Center, China Lake, to develop and fabricate additional supersonic test vehicles (STV) that are derivatives of the air-launched low volume ramjet supersonic facility missile (ALVRJ/STM). Activity at Vought during this reporting period has been low as the Navy continues to test and develop the MICRAD terminal guidance system for the next vehicle, the STV-G.

TARGET DRONE

A vehicle that employs the ALVRJ/STM-developed integral rocket liquid fuel ramjet propulsion system and the recovery system that has been preliminarily designed for the STM is proposed to the Navy as a near term solution to the supersonic target drone problem.

PERIMETER DEFENSE MISSILE (PDM)

Vought continued in-house studies of longer range alternatives to the Phoenix and Standard missiles for perimeter defense. These alternatives employ ALVRJ/STM-developed integral rocket liquid fuel ramjet propulsion systems. The Phoenix alternative uses the Phoenix missile front end including the guidance and warhead. It would be carried on the F-14 aircraft. The surface launched version is box launched. Phoenix and Standard missile guidance and warhead are options.

MULTIPLE LAUNCH ROCKET SYSTEM (MLRS)

The multiple launch rocket system (MLRS) is a battlefield rocket system for the U.S. Army. The MLRS Flight Test Program during the validation phase consisted of 127 engineering development and scoring-round flights at White Sands Missile Range. The scoring-rounds demonstrated accuracy met the validation phase specification requirements. As of this date, the MLRS Maturation Phase Flight Test Program has successfully launched 62 rockets (52 with the XM77 warhead and 10 with the AT2 warhead). The MLRS maturation phase flight test results indicate that the overall drag is near that expected. Monitoring of drag will continue to verify analytical and wind-tunnel test results. Slight adjustments have been made in normal force and pitching moment coefficients relative to the wind-tunnel data in order to achieve the best trajectory match.

The best estimate of boost phase stability data currently shows negligible plume effects, although earlier full-scale wind-tunnel testing with a normal flow jet plume simulator had indicated strong plume effects. This area of aerodynamic definition will continue to be studied closely during the Maturation Phase.

ASSAULT BREAKER

Vought is currently in the Flight Test phase of a demonstration contract with the Army Missile Command involving development of a submissile and submunition dispenser and the T-22 missile delivery system (assault breaker). The overall program is under the sponsorship of the Defense Advanced Research Projects Agency (DARPA). Vought is using a 22-in. diameter vehicle which is a Lance/SIG-D missile derivative. Vought recently completed the first two of the scheduled six flight test demonstrations at White Sands Proving Grounds, New Mexico. Both tests were highly successful. The tests involved supersonic flight of the T-22 missile to a precise aimpoint above the target area, controlled dispense of quantities of subweapons and delivery of the subweapons within prescribed circular and linear laydown patterns. Terminally guided submissile (TGSM) and skeet delivery vehicle assembly (SDVA) submissiles and submunitions, respectively, were dispensed during the tests from the exposed forebody dispenser bays. A significant test result has been verification that subweapon separation is quite similar to preflight estimates predicted using analytical techniques. This includes some occurrences of subweapon tumbling at eject which were predicted via the combined modeling of flight condition, local flow interference, ejector mechanism, and subweapon aerodynamic effects. Substantial prior supersonic wind-tunnel airload and separation testing; specialized trajectory routine development; and ejector mechanism testing, including sled qualification tests, were instrumental in the separation prediction efforts.

CORPS SUPPORT WEAPON SYSTEM (CSWS)

In 1980 Vought was awarded a contract by the U.S. Army for a preliminary definition of the corps support weapon system (CSWS). The Vought postulated CSWS requirements, system structures, and system designs have been developed through mission area analyses and system definition studies. Vought analyses have examined time and space relationships, reconstitution, cumulative delay effects, and impacts on Warsaw Pack command structure and decision making. Input data, including the CSWS mission element needs statement (MENS), target list for CSWS, system threat assessment report, and the Europe I, Sequence 2A, and Europe III, Sequence 2A scenarios from the scenario-oriented recurring evaluation system (SCORES) have been provided by MICOM and TRADOC.

The Vought-postulated solution to the CSWS requirement is Lance II which is currently in prototype flight-test status as the T-22 assault breaker end game demonstration vehicle. This early testing, along with prior simplified inertial guidance demonstration (SIG-D) flight tests and continued use of Lance inventory assets, establish the basis for a multiphased evolution of the current Lance operational system into Lance II.

CONVENTIONAL STANDOFF WEAPON (CSW)

Vought is conducting studies for an air-launched variant of the Assault Breaker/CSWC missile called the conventional Standoff Weapon (CSW). It is solid rocket powered and can be launched from F-4, F-15, F-16, and B-52 airplanes. The missile has various alternative submunition warheads to be employed against such targets as airfields, bunkers, radar complexes, tanks, etc.

VOUGHT HYPERVELOCITY MISSILE

Vought is developing a family of small hypervelocity missiles that travel in excess of 4000 ft/sec and can penetrate rolled homogeneous armor of thickness used by the majority of targets on a battlefield. Vought is currently under contract to both the Armament Division, Eglin AFB, Florida and the Ballistic Missile Defense Advanced Technology Center at Huntsville, Alabama.

Two series of wind-tunnel tests have been conducted to support programs at Vought. The first series was conducted over a Mach number range of 0.8 to 4.8. The model was tested both spinning and nonspinning with angles of attack up to 20 deg. This test provided both basic aerodynamic characteristics and Magnus effects The second series tested the boundary layer interaction effects of the impulsive thruster control system. These tests indicated small effects on the basic thruster impulse over the Mach number range 0.8 to 4.8.

SMALL CALIBER GUIDED PROJECTILE (SCGP)

Vought has been conducting studies and wind-tunnel tests of a small caliber guided projectile (SCGP) during the past year. A proposal has been made to the Army for further studies and Vought is responding to an Air Force request for proposal for studies, tests, and demonstrations. The Vought SCGP design concept employs spin stabilization and uses free stream dynamic energy for maneuvering as opposed to pyrotechnic and/or squib maneuvering devices.

PASSIVE ACTIVE ALL WEATHER SEEKER(PAAS) GUIDANCE TECHNOLOGY
INTERFACE DESIGN TRADES

Vought, conducting a design trade study of the guidance technology interface for the passive active all weather seeker (PAAS) under contract with the Armament Division at Eglin AFB. The program will determine the critical trades in guidance technology interface design factors which will be most valuable in blending the PAAS into a ducted rocket-powered missile for Range Improved Air-to-Air Technology (RIAAT) demonstrations.

LOW OBSERVABLE MISSILES

Vought Corporation is under contract with Air Force Wright Aeronautical Laboratory (AFWAL) FIMG to evaluate the impact of low observable considerations on air launched strategic missiles. The object is to determine the observable levels required, the degree to which those levels can be obtained through shaping, and the extent to which aerodynamic performance will be compromised by observable considerations.

MARTIN MARIETTA AEROSPACE

CANNON LAUNCHED GUIDED PROJECTILES

Martin Marietta is currently developing a cannon launched projectile (GP) for the Navy. The program is nearing the initial production stage.

The Navy GP is canard controlled and uses semiactive laser guidance during the terminal phase of flight to overcome flight dispersions and target location and motion induced errors. The target is illuminated by an air or ship borne laser. Laser energy reflected by the target is sensed by the seeker and proportional navigation is used to develop steering commands for the canards. A steerable two axis gimballed gyro measures the line of sight rate which is the basis of the guidance and control scheme. The motor is ignited at a fixed time after launch and target acquisition is anabled at a point which is chosen at launch. The acquisition system is enabled such that the target is in the field of view. Immediately thereafter, the canards are deployed and the guided portion of flight begins.

The Navy projectile is powered and operates without roll control. The latter feature translates into a requirement that the roll rate diminish from as much as 20 Hz at launch to less than 1 Hz within two seconds of launch. During the early seconds of flight the canards are not deployed and so the primary source of induced roll is the tail fins which will tend to develop twist and/or camber during the launch or deployment process. As a matter of reference it is noted that approximately 4.7 minutes of twist <u>or</u> 9 minutes of camber will produce a roll rate of 1 Hz. Therefore, control of tail surface "free play" and prediction of resulting induced moments must be fairly precise.

During the current engineering development program there have been 46 fully guided test firings including 20 shipboard shots conducted entirely by Navy personnel. Over 80 percent of the shots were hits.

DISPENSER LAUNCHED SUBMUNITIONS

Martin Marietta is developing a multiple warhead delivery system to deploy several types of submunitions. A multiyear IR and D program is underway which addresses technology issues related to such systems. The work includes a series of wind-tunnel and sled tests in which submunition aerodynamic and trajectory characteristics are measured.

The submunition dispenser is a guided, rocket propelled missile. The warhead section is divided into three tandem bays and each bay contains some submunitions. The terminally guided missile is typical of the submunitions to be dispensed. The submunition motion in the vicinity of the dispenser must be understood because the perturbation that occurs while transversing the dispenser flowfield may conceivably cause: collisions with the dispenser, dispersion in the submunition trajectory, and/or damage to gimballed guidance sensors.

To examine the submunition behavior during the ejection process a series of two-sting wind-tunnel tests were conducted in the Vought High Speed Tunnel at Mach 1.3 and 2.0. Ejection velocities from 7 to 36 ft/sec were examined. In general, the results indicate that appropriate provision for local flow conditions and submunition stability levels allow safe dispensing at least up to Mach 2.0.

To demonstrate the dispensing in a dynamic environment, a sled test was conducted at the Naval Weapons Center, China Lake track. Successful dispensing was demonstrated at Mach 1.5 and the observed motion confirmed wind-tunnel and analytical results.

HONEYWELL, INC.

G.D. Stilley

TMD DISPENSER

Honeywell has essentially completed development of the (TMD) spinning dispenser for the Air Force. Over 100 flight tests have been completed and show generally satisfactory, stable performance. The dispenser uses foldout fins which are canted at a selected event time or altitude to spin up the dispenser and, therefore, provide pattern size tailoring. It is currently being used for GATOR, ACM, ERAM, and AMIS submunitions. It is compatible with a wide range of delivery A/C, bomb racks, and delivery conditions.

SLAPC DISPERSAL MECHANISM

The TMD is the first dispenser with the capability to tailor ground pattern size to the mission, by use of variable dispenser spin rate. Static tests have been completed and sled tests are being prepared.

NUMERICAL AERODYNAMICS

Applications expertise is being developed in the area of numerical aerodynamics by a project involving installation of the HESS code developed under DTNSRDC auspices. This panel-oriented code was selected as most suitable for the users involved at the time. The current approach is to model dispenser weapons such as TMD.

ORIENTATION AND STABILIZATION FOR SENSOR FUZED SUBMUNITIONS

A significant effort, in-house and contractual, has gone into the development of an orientation and stabilization (O/S) device to provide descent and spin control for a family of sensor fuzed submunitions which use advanced standoff warheads and millimeter wave and/or infrared sensors to attack armored targets. These weapons use a spiral scan (along the centerline) of the ground below to search for the target.

WRAPAROUND FIN STABILITY

Another class of spiral scan submunition has extended at least one step beyond the effects of wraparound fins. In this case the scanning sensor was offset from the centerline, while the warhead axis was parallel.

The first manifestation of wraparound fin effects was that spin rate control did not require canting because the flare put the fin effectively at an angle of attack. Because of this, spin was in the opposite direction from that expected. Spin rate control was provided by varying the amount of rotation about the longitudinal hinge line.

The theoretical analysis required adding some terms to the standard four-fin simulation model to account for induced side moments. In addition to six-degree-of-freedom simulation, gas bearing three-degree-of-freedom wind-tunnel models were used in studying the problem.

NIELSEN ENGINEERING AND RESEARCH, INC.

M.H. Hemsch

HIGH ANGLE-OF-ATTACK WING-ALONE DATABASE

In cooperation with NASA Ames Research Center under the sponsorship of the Army Research Office, the Army Missile Command and NAVAIR, Nielsen Engineering and Research, Inc. (NEAR), and NASA Langley Research Center are conducting a series of tests to obtain a comprehensive database for wings of the sort typically used on high performance missiles. The angle of attack range if 0 to 60 deg, the Mach number range 0.6 to 4.5, and the aspect ratio range is 1/2 to 4. Tests of a series of pressure wings have been completed at Langley for Mach range 1.6 to 4.6 (Stallings and Lamb, Jul 1981). The Mach range 0.6 to 1.6 tests will be conducted at NASA Ames in the fall of 1981.

TRISERVICE DATABASE FOR PROGRAM MISSILE

In cooperation with NASA Langley and NASA Ames under the sponsorship of all three services, coordinated by the Office of Naval Research, NEAR is preparing a series of tests on a generic cruciform missile model to supply a necessary database for the comprehensive missile aerodynamics prediction code known as PROGRAM MISSILE. The test parameters will be $M_\infty = 0.6 - 4.6$, $\alpha = 0 - 45$ deg, full model roll and fin deflections from -40 deg to +40 deg. Three tunnel entries at NASA Langley and three at NASA Ames will be required to complete the database. The first entry at NASA Langley is scheduled for November 1981. The first entry at NASA Ames is scheduled for January 1982.

DEBRIS AERODYNAMICS

Under the sponsorship of NAVSEA, NEAR is improving and validating a computer program is has developed for the six-degree-of-freedom aerodynamics characteristics and trajectories of missile fragments. Ballistic range and water tank tests are being used to validate the code. Under the same contract, NEAR will determine the debris trajectories of target fragments resulting from the operation of destructive flight termination systems.

ANALYTICAL EXTENSION OF PROGRAM MISSILE DATABASE

Under the sponsorship of NWC and ONR, NEAR is analytically extending the fin database of PROGRAM MISSILE to $M_\infty = 4.6$ and $\mathcal{R} = 4$. Modified strip theory and flow field data generated by the Klopfer-Nielsen Euler code are used to generate the necessary "data." The new data will be limited to body angles of attack between 0 and 20 deg.

EULER CODE STUDIES OF VORTICITY FLOWS IN MISSILE AERODYNAMICS

Under the sponsorship of ONR, NEAR has been making a study of applying the Euler equations to vortical flows such as leading-edge separation and vortex roll-up, symmetric vortex separation from bodies of revolution, and wake flows. The latest studies are directed toward the flow over a wing-body combination when body vortices and fin leading-edge vortices are both present.

ANALYTICAL AND EXPERIMENTAL INVESTIGATION TO REDUCE MISSILE FIN HINGE MOMENTS

Under the sponsorship of AFFDL and ONR, NEAR is conducting an investigation to explore, systematically, the benefits achieved in tailoring fin planform so as to achieve reduced fin hinge moments without compromising controllability. Phase I of the work, which involves development of a method for predicting fin hinge moments, is well underway. Phase II involves the use of prediction methods for exploring fin planform tailoring and will include testing of the most promising fin shapes.

CONTINUED DEVELOPMENT OF MISSILE AERO-LOADING PREDICTION PROGRAMS (DEMON)

Presently, work is nearly finished on version DEMON3 of the set of programs designed to compute pressure distributions and component loads acting on complete missile configurations. In this effort, sponsored by NASA Langley, the earlier version, DEMON2, is extended to handle bodies with noncircular cross section with triplet panels. Certain geometrical restrictions are relaxed and a new vortex tracking module is developed to determine vortex paths along body-fin and body-alone portions of the missile for cases involving arbitrary cross sections and fin locations. Work to be performed during the next year will include addition of after-body vortex shedding effects, account for fin leading- and side-edge vortices, streamline a semiproduction version designated NSWCDM limited to cruciform canards and tails on circular cross section bodies, and extend the theoretical approach to the high supersonic and hypersonic range.

NASA LANGLEY RESEARCH CENTER

J.M. Allen

SUPERSONIC STORE CARRIAGE AND SEPARATION

An investigation is being conducted at NASA Langley Research Center to provide a near-field database of a generic nature that is applicable to store carriage and separation problems at supersonic speeds. Early results indicated the value of a silhouette cavity as opposed to a shallow box cavity, however, many questions still need to be addressed (e.g., cavity geometry, model geometry, and model attitude). Current work includes the effect of depth and demonstrated that the deeper cavity improved the separation characteristics. Future research will include cooperative efforts with the Air Force Weapons Laboratory and the Air Force Flight Dynamics Laboratory.

THEORETICAL MISSILE AERODYNAMICS

An effort is underway to develop and verify computational methods for high-speed missiles. Our present capabilities include operational codes, and force and moment data, on circular bodies with cruciform fins. Our current effort is to develop the analytical tools to handle elliptical bodies with monoplanar wings and interdigitated tails, and to conduct a parallel experimental program for code verification. The ultimate goal is to extend these codes to handle bodies and fins of arbitrary shape.

The experimental effort at Langley is a pressure and vapor-screen test on an elliptical body with monoplane wings and interdigitated fins. A part of the theoretical effort is the development of a vortex shedding code for missile fore-bodies of arbitrary shape. This code will provide not only the characteristics of the shed vortices, but also surface pressure distributions including the effects of the shed vortices.

A separate effort has been made to assess the ability of linear theory codes to calculate the lateral-directional stability characteristics of simple wing-body-tail configurations.

A joint experimental program with the military and industry will provide sub-sonic transonic and supersonic data for complete missile configurations at high angles of attack. Elements of this program will include overall force measurements, as well as fin hinge and bending moments.

AERONAUTICAL PROPULSION INTEGRATION

Langley has completed the testing of the aero/propulsion integration model and all publications are in process. This work was presented by NASA Langley at the 12th Aeroballistics Symposium held at DTNSRDC May 12-14, 1981.

ADVANCED AERODYNAMIC CONCEPTS

The need to provide a better aerodynamic match between longitudinal and lateral-directional stability and control has led to studies of configurations that lend themselves to conformal carriage and offer the promise of low radar detection characteristics. The current effort in this area is an experimental study of the effects of replacing the straight-edged fins with low radar, curved-edge fins. Preliminary results, are that no degradation aerodynamic performance was observed with the low-radar fins.

GENERAL DYNAMICS, POMONA DIVISION

D.J. Trulin

TERMINALLY GUIDED SUBMISSILE (TGSM)

This munition is used as part of the Assault Breaker weapon system. A dispenser is used to fly a cluster of TGSM's over the FEBA to the location of the enemy's massed armor. The dispenser then ejects the TGSM's which search, acquire, and guide to a target.

One of the most interesting aerodynamic aspects of the TGSM is the use of a General Dynamics developed "Batwing" (patent pending). The packaging and warhead requirements of the Assault Breaker weapon system left little volume for TGSM aerodynamic surfaces. Because high maneuverability at low speeds was desired, a large wing surface was required. The use of the General Dynamics Batwing was a perfect match. This triangular wing is comprised of two rods for the leading and trailing edges around which is stretched a fabric skin. The rods are so designed that they may be folded into a small shallow depression in the body. A thin metal cover is placed over the folded wing before storing in the dispenser. The cover is ejected in flight by first firing a squib that releases the cover latch. The spring loaded wing then pushes the cover off into the frustrum where it is swept aft. The wing continues to erect and then locks in its flight configuration. The erection concept has been tested and proven in the wind tunnel. Additional wind-tunnel testing of the erected fabric wing was also performed to measure force and moment characteristics; no anomalies were found from that of a solid wing.

OTHER WORK

The Standard Missile Block II programs are progressing smoothly. Their development has been discussed in recent meetings.

The RAM missile is continuing in its engineering development with several recent GTV flight successes.

General Dynamics also reported that the STINGER and VIPER Missile Systems are entering the production phase. The Rolling Airframe Missile is continuing in its engineering development with several recent successful, guided flight tests.

THE ANALYTICAL SCIENCES CORPORATION (TASC)

C.F. Price and A.R. Mitchell

The Analytical Sciences Corporation (TASC) is involved in improving aerodynamic models by appropriately processing flight test data. The preflight wind-tunnel model is used to predict the missile trajectory; any deviations between the predicted trajectory and the actual measured trajectory are used to modify the models through some type of post flight processing.

In this general approach for determining the aerodynamic model from flight test data, input forces (thrust and aerodynamic forces) are applied to the missile to cause it to fly a trajectory. The actual missile is instrumented with a variety of sensors whose outputs are telemetered to a ground-based data collection facility. Parameterized models are derived which describe both the response of the missile to the input forces and the characteristics of the sensor outputs. Then, in the post-flight processing stage, estimates of the parameters are obtained by some type of model fitting algorithm.

AERODYNAMIC COEFFICIENT ESTIMATION SOFTWARE (ACES)

The Analytical Sciences Corporation has developed an Aerodynamic Coefficient Estimation Software (ACES) package, based on the extended Kalman filter (EKF), for estimating the model parameters. The EKF makes use of all available statistical information about the sensor measurement accuracy, initial condition uncertainty, and disturbances to generate a nearly optimal (minimum variance) estimate of the parameters.

The ACES package has been and is being applied to a variety of missile and projectile applications. In the case of projectiles, the measurements are derived from an instrumented test range, such as the Aeroballistic Test Facility at Eglin Air Force Base. The missile applications include Sparrow, GBU-15 glide bomb, Multiple Launch Rocket System (MLRS), AMRAAM, and HELLFIRE. Projectile data have been processed for 20 mm and 30 mm rounds, and for a number of scaled missile models which are fired as projectiles.

ROBUST AUTOPILOT ALLEVIATION OF RADOME ERROR SLOPE COUPLING IN BANK-TO-TURN MISSILES

Alleviation of radome error slope coupling in bank-to-turn missiles is a subject of major concern to the Navy and the Air Force. A significant, preliminary advancement in this area was achieved by TASC as part of its Range Improved Air-to-Air Technology (RIAAT) effort performed for the Air Force Systems Command, Armament Division.

The Navy and Air Force are interested in future enhancement of AMRAAM intercept capabilities to achieve better seeker performance in bad weather and against jamming, and to realize better propulsive performance for greater range.

One challenge is presented by potentially severe radome boresight error that can be intrinsically present in an affordable broadband radome of efficient aerodynamic shape. A second challenge is presented by bank-to-turn steering, which may be required instead of skid-to-turn steering because of inlet recovery constraints imposed by axially asymmetric rocket-ramjet designs. Bank-to-turn steering can exacerbate radome boresight error slope to autopilot coupling for classical autopilot designs.

One promising approach to a modern autopilot design was partially defined and evaluated in TASC's RIAAT effort. This approach employed a unique modern autopilot synthesis technique to create a robust controller design for the alleviation of radome error slope coupling. The term "robust" means that stability with good performance is achieved over a wide range of uncertain, time varying radome error slope values. The RIAAT evaluation of TASC's robust autopilot design used a low order Fourier model of the radome boresight error and a planar motion, three-degree-of-freedom simulation.

The Analytical Sciences Corporation has successfully proposed a follow-on effort to RIAAT in the area of robust autopilot design, "Passive-Active All-Weather Seeker (PAAS) Guidance Technology Interface Design Trades Study." The PAAS effort will extend the RIAAT robust optimal autopilot synthesis technique to create a multiloop controller that is robust with respect to the full, three-dimensional radome boresight error statistics.

The beyond-visual-range (BVR) guidance problem is currently receiving major emphasis as a result of the Advanced Medium Range Air-to-Air Missile (AMRAAM) program and follow-on programs. Competing AMRAAM missile configurations are presently undergoing validation phase tests and evaluation. The missile configurations being implemented by both Hughes and Raytheon will include command-update inertial guidance for midcourse steering and an active radar terminal seeker.

The Navy is interested in range enhancement of AMRAAM through liquid rocket ramjet technology, and is presently pursuing this goal in the Advanced Common Intercept Missile (ACIM) Demonstration Program. The Air Force approach to AMRAAM range enhancement involves ducted rocket ramjet technology, as defined in the Range Improved Air-to-Air Technology (RIAAT) program. Both the Navy and Air Force programs include command-update inertial midcourse guidance and active radar seeker terminal guidance based on AMRAAM.

The Analytical Sciences Corporation's BVR guidance studies have shown that optimal trajectory shaping promises a payoff of extended range with more favorable end game conditions. Optimal trajectory shaping was one of the tasks performed on TASC's RIAAT study. As an initial proof of concept, pitch plane dynamics were controlled by angle of attack and throttle setting to maximize range at burnout. This effort emphasized numerical optimization techniques which would reliably converge. The study then considered whether the code could be implemented in real time with on-board VLSI microprocessor technology

WORKED PLANNED FOR THE FUTURE

The Analytical Sciences Corporation has won the Guidance and Control for Beyond-Visual-Range Tactical Missiles competition, contracted by the Air Force Systems Command, Armament Division. The contract enables TASC to extend its optimal trajectory shaping work performed in the RIAAT study. The new effort will develop and demonstrate six-degree-of-freedom optimal trajectory shaping with realistic final time constraints for hand-over to terminal guidance (i.e., the end game). The constraints will include allowable bounds on line-of-sight rate, terminal acquisition range, and flight path angle. The cost function will be a weighted sum of kinetic energy at hand-over and midcourse flight time.

MISSILE STABILITY AND PERFORMANCE PANEL RECOMMENDATIONS TO NAC

The following recommendations were generated by the panel during the meeting.

1. RECOMMENDATION:

Develop and experimentally verify engineering prediction methods for the external aerodynamic characteristics of airbreathing missile configurations at arbitrary bank and control deflection angles, to high angles of attack, extending into the hypersonic regime.

BACKGROUND:

In order to meet future projected threats, the Navy is designing airbreathing missiles. Engineering prediction methods for the development of such designs and for tradeoff studies is nonexistent. The combination of body buildup testing, flow visualization testing, and use of computational fluid dynamics codes has recently made the development of such engineering methods feasible. To support these predictions techniques, the following experimental work is recommended: force and pressure measurements on hypersonic ramjet configuration models providing a wide range of external geometric shapes; flow visualization of vortical regions; and additional body buildup measurements of component effects.

2. RECOMMENDATION:

It is recommended that an experimental investigation be initiated, in the low subsonic region, to measure forces or pressures on missile components (body, body-wing, etc.) at constant angles of attack with crossflow Reynolds number varied from subcritical to supercritical. Suitable test models are probably in existence.

BACKGROUND:

The interest in this type of information stems from the large mismatch between the Reynolds number in subsonic tunnel testing and the full-scale Reynolds number early in launch. Typically, at a given angle of attack, the crossflow Reynolds number in the tunnel is subcritical, whereas in flight, it is supercritical. Some prominent investigators have proposed methods to calculate the Reynolds number effect on inclined configurations (at very low speeds) but there are no experimental data in the literature to evaluate their approach.

3. RECOMMENDATIONS:

Assess alternative methods for reducing the sensitivity of missile intercept performance to radome boresight error slopes. The methods to be considered should include at least the following:

(a) Increase airframe maneuver level per degree angle-of-attack

(b) Alleviate radome error slope and autopilot coupling through application of robust linear quadratic gaussian (RLQG) autopilot design techniques. The RLQG autopilot maintains good stability characteristics with small performance penalties by minimizing the expected value of a "payoff" function in the presence of boresight error slope uncertainties.

(c) Compare apparent target motion with an on-board model to provide a basis for filtering out erroneous target line-of-sight rate information. This can be done because target motion is limited by known factors.

(d) Reduce the effect of boresight error slope by applying an adaptively estimated correction term in the tracking loop. This would be achieved by introducing high-frequency waves either through the missile control subsystem and cross-correlating the input either with tracker error signal frequency content.

(e) Store the radome boresight error characteristics on board in the missile guidance computer, and directly correct for the production errors in real time.

BACKGROUND:

The cost of current missiles designed to intercept high-altitude targets (e.g., SM-2) is significantly increased by the need to "tune" the radome of each radome-seeker assembly in the production line, as well as the need to hold very tight production tolerances. Also, evolution of the high-altitude threat is expected to result in the need to improve missile intercept performance in the presence of current boresight error slope levels.

Several airframe and autopilot-guidance electronics features show promise in influencing the stability of the guidance loop in the presence of boresight error slopes; these ideas need to be compared and traded-off individually and in combination to determine the potential payoffs in terms of radome and missile performance and production cost.

4. RECOMMENDATION:

Engineering design guidelines should be developed for the bounds of aerodynamic parameters required for optimum maneuverability performance of tactical missiles from a flight control perspective. The sensitivity of these bounds should be obtained for different candidate levels of flight control system complexity.

BACKGROUND:

High performance missiles are often severely limited in their maneuverability by the inability of the flight control system to handle strongly-varying aerodynamic lateral-directional and control cross-coupling characteristics. If appropriate bounds were known and preliminary airframe designs were constrained to fit those bounds, missile airframes could be designed which could be optimized both for maneuverability and controllability.

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1981 REPORT TO THE

NAVY AEROBALLISTICS COMMITTEE

FROM THE

STRUCTURES AND AEROELASTICITY

PANEL

INTRODUCTION

The panel met at the David W. Taylor Naval Ship Research and Development Center on 6-7 October 1981. Members present reported on accomplishments in their respective activities during the past year and formulated technical recommendations for consideration by the NAC. These are reported here.

The attendees were:

Mr. A.A. Anderson (Chairman)	Pacific Missile Test Center
Mr. M. Bernstein	Grumman Aerospace Corp.
Dr. Charles Blackmon	Naval Surface Weapons Center
Mr. W.C. Caywood	Johns Hopkins University Applied Physics Laboratory
Mr. Paul Hahn	Martin Marietta Aerospace Orlando, Florida
Mr. E.L. Jeter	Naval Weapons Center
Dr. Paul M. Kenner	Vought Corp.
Dr. R.F. Jones, Jr.	David W. Taylor Naval Ship Research and Development Center
Dr. Sam McIntosh	Nielsen Engineering and Research, Inc.
Dr. Dan Mulville	Naval Air Systems Command
Mr. Sam Owen	David W. Taylor Naval Ship Research and Development Center
Mr. R.M. Rivello	Johns Hopkins University Applied Physics Laboratory
Mr. D.H. Sanders	Raytheon Co.
Mr. S.N. Schwantes	Honeywell, Inc.
Mr. J. Schmich	McDonnell Douglas Astronautics, Co., East
Dr. L.V. Schmidt	OASN
Mr. George S. Seidel	Naval Air Development Center
Mr. C.M. Standard	Vought Corp.
Mr. W.H. Terrill	General Dynamics, Pomona

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER (DTNSRDC)

J.H. Ma and R.F. Jones, Jr.

DEVELOPMENT OF A THERMAL DISTORTION COMPUTER CODE

A finite element code to account for thermal expansion in a solid has been developed. The program is based on a two-dimensional model using a second, or higher order, interpolation function in the element space that will allow a linear as well as a nonlinear temperature gradient to be prescribed in a solid body.

Using this code, the hot spot in the landing deck due to the concentrated heat load, such as those generated by high temperature jet exhaust (2800°F or hotter) can be readily and more realistically determined.

NONLINEAR FINITE-ELEMENT STRUCTURAL ANALYSIS USING COMPUTER GRAPHICS

A system for performing nonlinear finite-element structural analysis in an interactive, graphics-oriented computational environment has been developed. The system constitutes a network of integrated software processors, referred to as GIST, which enable the user to perform a wide variety of operations accessible through a common "command" (or "control") language. Many of these operations are actually performed by independent processors which are linked through a "global database" to behave as an integrated system.

NAVAL SURFACE WEAPONS CENTER

C.M. Blackmon

STRUCTURAL TECHNOLOGY FOR ROTATING BAND EVALUATION (STROBE)

In recent years the Navy has initiated programs to replace the copper-gilding metal rotating bands currently used on projectile bodies. The objective of the STROBE program is to develop a structural design methodology for rotating bands using new nonstrategic plastic materials. The design methodology addresses material characterization, material modeling, analysis methods, and innovative design concepts.

In order to solve these problems new computer programs have been developed for the analysis of shedding and fragmentation, and engraving of plastic rotating bands. Finite element codes, which incorporate large deflections, finite strains, elastic-plastic material models, and interface elements for modeling gaps and sliding friction, have been developed. These codes have been used to conduct analyses for two projectiles. Material property characterization data requirements have been defined and properties for two materials of current interest were obtained. This work has been documented in a Rotating Band Design Methodology Handbook recently released.

Further information on the project may be obtained by contacting R.J. Edwards, Code K22, White Oak, 202-394-1901.

ADVANCED POINT DEFENSE

The current program is an analytical study effort which is concerned with a Navy Tactical Surface-to-Air Guided Missile System with a time frame applicable to the years 1990-2000. Effective defense against the threat is recognized as a high priority Navy requirement. It is highly desirable to perform several missions (surface-to-air and air-to-air) with a single missile configuration or with missiles sharing a high degree of commonality. It is envisioned that this missile will contain common G&C and ordnance sections, but may have different propulsion and airframe designs to accommodate the different launch environments from air and surface platforms.

A contract was negotiated with the Missiles Systems Division, Raytheon, to provide a preliminary airframe design capable of meeting the performance requirements specified.

Further information on the point defense effort may be obtained by contacting Rick Solis, Dahlgren, 703-663-8166.

METAL MATRIX COMPOSITES

The national technology base community has been active and successful in new material and structural developments in recent years. Integrating these successes into viable design options to enhance future weapon systems capabilities is now a priority mandate for the Department of Defense (DoD). This undertaking will involve the fabrication and testing of demonstration hardware, production of components for testing, and the execution of those activities necessary to ensure that systems performance will be satisfactory, reproducible, and reliable.

Throughout the past decade the DoD has manifested a strong interest in developing metal matrix composite (MMC) materials and has invested an estimated 70 million dollars in this technology over the past ten years. In the late 1970's a MMC "thrust" was implemented to further accelerate the pace of developmental efforts. The results of the last three years' efforts, directed by the Army, Navy, Air Force, and Defense Advanced Research Projects Agency (DARPA), have advanced the MMC community rapidly toward systems applications. Present efforts focus on making this new technology more cost effective.

The program to develop MMC's for advanced Navy weapon systems was initiated in 1974 by the Naval Sea Systems Command. Subsequent programs are now being managed by the Office of Naval Research and by the Naval Air Systems Command. Funding which supports the overall effort invokes basic research, exploratory development, advanced development, and manufacturing technology categories.

Technical direction for these efforts is the responsibility of Navy Laboratories and the technical work is performed by an in-house, academic, and industrial cartel of specialists. The Surface Weapons Center is the MMC lead-laboratory for the Navy. Efforts in MMC applications analysis have been conducted which show that significant benefits can be realized through the use of these new materials. Examples of systems which have been shown to benefit are tactical missiles, hydrospace structures such as mines and torpedoes, and strategic missile components. The Navy operational requirements stress a need for improved structural materials which make more efficient use of structural mass to avoid weight, cost, and performance penalties.

Further information MMC may be obtained by contacting the Block Principal, John Foltz, White Oak, 202-394-2219 or for information relating to missile applications, Charles Blackmon, Dahlgren, 703-663-8285.

NAVAL WEAPONS CENTER REPORT

E.L. Jeter

STRIKE WARFARE BLOCK - METAL MATRIX COMPOSITE TECHNOLOGY

The Strike Warfare Block continued to support advanced structural concepts with the emphasis on metal matrix composites. In order to demonstrate feasibility of these materials, it was decided to fabricate on all-movable tail fin similar to one envisioned for the AIAAM mission. During the past year several parts were fabricated to evaluate producibility and joining techniques using metal matrix titanium skins and titanium honeycomb cores. Some data were obtained to evaluate the strengths of diffusion bonded joints between the metal matrix skins and solid titanium, representing leading or trailing edges or wing hub support structures. Tests were performed on parts with crushed cores to evaluate whether or not there was significant loss of strength for this process.

Current work, in progress, will demonstrate two different joining and fabrication techniques for a conceptual tail fin with both chordwise and spanwise tapers. One fin will be constructed with a crushed honeycomb core, while the other will be fabricated using a super-plastic formed four sheet process. An evaluation of these two processes will be made to determine which one is best in terms of cost and producibility, and one will be selected for full-scale fabrication of some actual tail fins. All of the work to date has been performed by McDonnell-Douglas Astronautics, St. Louis; however, the full-scale fabrication is expected to be a competitive bid contract.

STRUCTURAL MECHANICS RESEARCH - NONLINEAR FLUTTER ANALYSIS

This work has been funded through AIR-320B, and it consists of two parts. The first part concerns monitoring on-going research at Nielsen Engineering and Research Company involving experimental and analytical nonlinear flutter techniques.

The second part of this effort concerns the development of in-house capabilities for performing nonlinear flutter analyses. This in-house effort involves the application of describing function techniques to model structural nonlinearities in the supersonic flight regime and to develop parametric analyses of the effects of root bending and torsion nonlinearities of all-movable control surfaces in supersonic flight. This work is similar to that performed during past years by MDAC for the HARPOON tail fin in subsonic flight, but this study will focus on two surfaces, a HARM wing and a SPARROW-like tail fin, in supersonic flow.

Much of the effort this year has been spent on acquiring a general flutter analysis capability for arbitrary planforms in supersonic flow. This seemingly easy task has been complicated by unplanned factors that arose from the use of off-the-shelf software. For example, the COSMIC version of NASTRAN was planned for use on this effort; however, considerable use of this code has led to the conclusion that errors exist in the UNIVAC version of this code (level 17.6) making the flutter package unusable for this effort. Three other codes have been acquired that will solve arbitrary planforms in supersonic flow, but as yet, these codes have not been successfully compiled and executed on the NWC UNIVAC 1110. Current work is continuing through the use of the Hughes Aircraft Corporation flutter codes that are somewhat limited in planform capabilities, while these other problems are resolved.

INDEPENDENT EXPLORATORY DEVELOPMENT - EXPERIMENTAL MODAL TEST METHODS

This in-house funded effort is closely related to the above flutter study. It centers around the application and evaluation of modern modal test procedures on missile wing-control section hardware that exhibits structural nonlinearities associated with quick-attach joints. Several experimental modal test procedures were acquired and implemented, including single point sine-dwell (SPSD), single point random (SPR), impact testing, and the Ibrahim time domain (ITD) procedures. Attempts were made to evaluate not only accuracy, but also ease of use of these procedures. In some cases the optimum hardware configuration was not available to make full use of the speed of some of these techniques. We were able however, to define various hardware configurations that would allow us to overcome these deficiencies. At the same time we were able to project where large payoffs could be made in implementing these techniques where adequate hardware was available. Because of these limitations, we were unable to make quantitative conclusions about whether or not some of these procedures would perform in our environment as advertised. This deficiency affected the conclusions about the ITD technique more than the others.

A brief summary of some of our conclusions follows:

1. For the nonlinear structure studied, the sine-dwell procedure was as easy to apply as any of the techniques, and it tended to produce the most consistently believable results. It did require more manual interaction with a computer to produce orthogonality checks and transfer functions.

2. The SPR procedure, as provided in SDRC MODAL software, can produce extremely good results when the structure is essentially linear, as in a cantilevered wing. It also produces a variety of data formats, and this can be very useful for evaluating the accuracy of a mode. The procedure is very fast at acquiring data, especially when multiple channels of response data are available.

3. Impact testing did not prove usable on the wing studied. The high frequency of the first mode (around 90 Hz) produced multiple hits on the hammer by confusing the FFT analysis procedure.

4. Results with the ITD technique were inconclusive because of the unwieldy procedures that had to be implemented due to our lack of appropriate hardware. The accuracy that was obtained on a simple beam structure were not on a par with the other procedures; however, it does have the benefit that it is not necessary to know the input force to make use of this technique.

NAVAL AIR DEVELOPMENT CENTER

G.S. Seidel, Jr.

APPLICABILITY OF MIL-A-8591 DESIGN CRITERIA TO STORES CARRIED ON CURRENT NAVY AIRCRAFT

There has been some concern expressed within the Navy that the inertia loads and air loads criteria contained in the specification MIL-A-8591 (revision F) are overconservative for Navy applications, resulting in inefficient designs and the need to authorize exceptions. Therefore, the Naval Air Development Center has been tasked to evaluate these criteria in terms of their suitability for current Navy aircraft. Four aircraft, the A-6, A-7, F-14, and F-18, are being studied to determine the loads that they can impose on external stores. Factors that affect these loads, both inertia and aerodynamic, include the geometry, speed, and maneuverability of the aircraft.

Results to date of the inertia loads study show that the flight inertia loads criteria are conservative by a margin of about 1.5 g. The most critical type of maneuver is a rolling pullout. This maneuver can produce high loads in all directions. Rolling acceleration performance is important, but the aircraft's actual capability is difficult to determine. Store inertia loads during catapult and arrested landing are dependent upon the elastic characteristics of the aircraft and supporting equipment, and are difficult to quantify in terms of specification parameters.

Aerodynamic load criteria consist of specified angle-of-attack and angle-of-sideslip values as a function of airspeed. In comparison with actual aircraft angles in critical maneuver conditions, procedure I was found to give improved agreement over procedure II. Even so, procedure I's angles were conservative by a factor of at least 2.0.

A METHOD FOR DETERMINING CRITICAL STORE CONFIGURATIONS FOR WING-STORE FLUTTER

The increasingly large inventory of wing-mounted external stores carried by current attack aircraft necessitates the development of more efficient methods for predicting critical configurations for wing-store flutter. Under Naval Air Systems Command sponsorship, Grumman has been exploring the approach of using optimum design search techniques to automatically determine critical store configurations. The reference contains a description of the application of the resulting method to a current Navy aircraft, the A-6E, and its inventory of stores.

The determination of critical store-flutter configurations may be viewed as an optimization problem in which the combination of permissible store parameters, that result in a minimum flutter speed for the aircraft under consideration, is to be found. The store properties are considered the "design variables" of the problem, on which the aircraft store inventory imposes certain limits or "constraints."

Flutter speed is chosen as the "objective or cost function" which is to be minimized. By treating the "design space" of permissible store properties, prescribed within the specified constraints, as a continuum rather than as an assemblage of many discrete points, numerical search techniques can be applied to determine the critical combination of stores that minimizes the objective function, i.e., results in the lowest flutter speed.

In this application the design variables were the mass, pitch moment of inertia, and center of gravity location of the store, and the pitch flexibility of the pylon. Inboard and outboard pylons were considered as a discrete variable. Results of the analysis pointed to the expected and some unexpected configurations as being flutter-critical.

A contract for extending the work described above is in preparation at NAVAIR. In the follow-on work, Grumman will add enhancement to the program in order to improve its efficiency, convert it to run on CDC computer equipment such as that available at NADC, and provide a user's manual. After this follow-on effort, the program will be on-line and available to users within the Navy community.

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY

W.C. Caywood and R.M. Rivello

HYPERSONIC MISSILE DESIGN SUPPORT

CONCEPTUAL DESIGN AND PERFORMANCE INVESTIGATIONS

Conceptual design and performance investigations of high-speed airbreathing missile design concepts for the wide area defense of the Navy's surface fleet in the late 1990's have been conducted by the JHU/APL and two of its subcontractors: the McDonnell Douglas Astronautics Company-St. Louis Division (MDAC) and Hercules, Incorporated, Allegany Ballistics Laboratory (HI/ABL). The concepts incorporate an innovative dual-combustion (subsonic and supersonic) ramjet propulsion system with an annular inlet and are compatible with the dimensional constraints of the Navy's vertical launch system (VLS) now under development. The MDAC and HI/ABL investigations addressed preliminary detailed design and performance of a weapon with a booster partially integrated with the missile. In the JHU/APL investigations, a tandem-rocket conceptual design was developed and compared with the integral-rocket configuration.

Weight equations for the tandem and integral-rocket concepts were derived as functions of missile and booster lengths. These were used with the results of boost trajectory analyses to determine relationships between end-of-boost Mach number and propellant mass fraction for the designs. The results were used to size the two design concepts for the weight and length restrictions imposed by the VLS. The tandem-rocket was found to have greater range capability than the integral-rocket when both were sized to the VLS constraints. In addition, the tandem-rocket is a simpler design and should have lower development and manufacturing costs.

The results of these preliminary investigations have been extremely encouraging, indicating that it is feasible to design a hypersonic missile that will meet the weight and dimensional constraints as well as the range and average speed requirements for far-term wide area naval defense. Current investigations are directed at optimizing range and speed performance by trajectory shaping and trade-off of end-of-boost speed, cruise speed, and configuration shaping to improve the lift-to-drag aerodynamic characteristics. Also, a chin inlet configuration, that would be compatible with a bank-to-turn guidance system, is being investigated. A preliminary layout has been completed and weight estimates of the configuration are currently being developed. The results will be used to conduct performance analyses that will allow comparisons with the annular inlet configurations previously investigated that assume skid-to-turn guidance.

EFFECT OF CRUISE MACH NUMBER ON STRUCTURAL WEIGHT

An investigation is being made to determine the effects that cruise Mach number (M_{cr}) has upon material selection and weight of structural components of a dual-combustion ramjet powered hypersonic wide-area-defense missile. Temperatures and loadings of critical airframe and engine components have been determined for assumed Mach-altitude design boundaries. These have been used with temperature dependent material properties to determine the critical design points on the boundaries and to determine trend lines for weight as a function of M_{cr}. In addition, the effects that M_{cr} and range have upon thermal protection system weight and volume are also being investigated. Results show that the structural weight: increases gradually with M_{cr} for $5 < M_{cr} < 6$, increases at a greater rate for $6 < M_{cr} < 7$, and experiences an extremely rapid growth for $M_{cr} > 7$.

SUPERSONIC MISSILE DESIGN INVESTIGATIONS

EX 104 ROCKET MOTOR DEVELOPMENT

The APL is providing technical assistance to the Navy in monitoring the development of the new EX 104 dual-thrust rocket motor for the Standard missile. The motor is being developed by Thiokol/Wasatch.

Thermal stress cracking of the thoriated (2 percent) tungsten nozzle throat inserts during static firing tests has persisted as a problem. Fortunately, when cracking of the nozzle exit cone insert occurs, the loose parts are trapped, resulting in a fail safe mode. Two different vendors have supplied the tungsten inserts, and although parts from both vendors have failed, the success record from one is better than the other. Several redesigns in geometry have been made, but the basic problem still exists.

Stress analyses have been conducted by both APL and Thiokol without predicting either failure stresses or the mode of failure. Preliminary indications are that there is little confidence in the material properties which are essential inputs to the stress analysis. Limited material property characterization tests are currently being conducted.

ASAR COMBUSTOR THERMAL TEST RESULTS

A test program has been conducted at the Hercules Incorporated/Allegany Ballistics Laboratory to determine the propulsion characteristics of an integral-rocket ramjet for use in the ASAR missile concept.

In conjunction with these tests, the combustor liner of DC 93-104 was evaluated. Heat lamps were used to simulate external aerodynamic heating of a portion of the combustor case. The rocket-ramjet was successfully tested for 29 sec. The test was originally planned for 45 sec, but ramjet fuel flow rate was inadvertently reduced to one-tenth its normal value when a pressure reference line ruptured at 29 sec. The combustor case was instrumented with nineteen thermocouples with an additional six thermocouples located on the headcap. The important thermal results are:

1. During transition to ramjet propulsion a severe vibration removed all the 0.005-in. diameter thermocouples and over one-half of the 0.015 in. thermocouples from the case.

2. Prior to their removal, thermocouples located under the heat lamps showing case temperatures were as expected indicating the quartz lamps were able to simulate the desired aerodynamic heating.

3. Thermocouples on the headcap inlet ports agree well with previous data and indicate no "flashback" of combustor gases into the duct.

4. Headcap temperatures were much greater than expected indicating higher than anticipated ablation of headcap DC 93-104 insulating material.

SUBSONIC MISSILE (TOMAHAWK) DESIGN SUPPORT

UNDERWATER VERTICAL LAUNCH FROM AN SSN-688 CLASS SUBMARINE

Investigations are being conducted at APL to support the development of the Navy's new capsule launch system (CLS) for vertically launching Tomahawk missiles from the SSN-688 Class submarines. The system consists of 12 vertical launch tubes in the bow external to the pressure hull. Navy contractors are: Westinghouse-Sunnyvale for the launch capsule, General Dynamics-Electric Boat Division for the submarine launch tube design, and General Dynamics-Convair for the missile. In this program the structural design of the Tomahawk missile is assumed fixed and the launch system is being designed so as not to exceed the structural capability of the missile. Primary emphasis is given to underwater explosion shock survivability and to loadings encountered during fly-out from the launch tube under high ship speeds. Shock survivability is to be demonstrated in submerged shock test vehicle (SSTV) testing.

The APL underwater launch simulation originally developed for the Polaris and Poseidon program is being modified to accommodate the Tomahawk launch configuration. When completed, the simulation will accommodate a flexible missile (beam model) elastically supported in a flexible capsule (beam model) which, in turn, is itself elastically supported at discrete points to a rigid mount tube. Simulation runs for a rigid missile launched from a rigid capsule indicate that uniform cross flow velocities of up to 9 knots can be encountered without exceeding the structural bending capability of the missile. Launch performance under cross flow will be experimentally determined in underwater launch translator testing at San Clemente Island later this year.

SURFACE LAUNCH FROM VLS

The APL is also providing technical assistance to the Navy's Joint Cruise Missile Project Office to assure that the structural limitations of the Tomahawk missile will not be exceeded when launched from the vertical launch system (VLS) now being developed for Navy surface ships. Potential problem areas that are being addressed are underwater shock, vibration, and in-tube launch dynamics. The underwater in-tube launch simulation is once again being modified, this time to accept the surface VLS configuration, for surface launch, wind and ship motion are the disturbing forces. No simulation runs have been made to date.

MISSILE RADOME INVESTIGATIONS

MATERIAL SCREENING FOR HYPERSONIC TACTICAL MISSILES

An analytical screening investigation has been conducted to determine which radome materials might be usable on a hypersonic tactical missile. The screening consisted of evaluating a matrix of two radome configurations, three trajectories, and ten ceramic materials for four possible failure modes. The failure modes included thermal shock, melting, aerodynamic loading, and excessive boresight error change. The screening was accomplished with the unified radome limitations computer code (URLIM).

Materials evaluated were: Pyroceram 9606, Pyroceram 9603, Rayceram III, slip cast fused silica (SCFS), AS-3DX - a quartz silica composite, hot pressed silicon nitirde, reaction sintered silicon nitride, hot pressed aluminum nitride, sintered aluminum nitride, and Sialon 128. The radome wall thickness was set for a half wave in the K-a band for all materials. The SCFS was also studied in a full wave configuration. The missile's angle of attack was set to produce a lateral acceleration of 30 g's up to a maximum angle of attack of forty deg.

Excessive attachment loads occurred on Pyroceram 9606, Rayceram III, and AS-3DX. Pyroceram 9606 and Rayceram III were also limited by excessive temperature as was Pyroceram 9603. None of the materials examined were limited by thermal stress. The least sensitive material for boresight error (BSE) sensitivity is AS-3DX with a BSE sensitivity of 0.187 while the most sensitive material is sintered aluminum nitride with a BSE sensitivity of 3.19. For this study, the maximum allowable BSE sensitivity was set at 1.00. The most promising materials for all the criteria are: reaction sintered silicon nitride, SCFS, and Sialon 128.

STRUCTURAL AND RF PERFORMANCE OF THIN WALL RADOMES

Multimode guidance capability is a requirement for missiles that will satisfy the Navy's near and far-term area defense needs, which implies the use of thin walled radomes. Structural analyses were conducted to determine the minimum wall thicknesses that are required to carry the aerodynamic loadings during sea level flight at speeds from M2 to M6 while undergoing a 30 g maneuver. Three radome shapes were investigated: von Karman with length-to-diameter ratios of 2.1 and 3.0, and a hemisphere. Of interest were base diameters of 7.5, 13.5, and 19.5 in. and flight Mach numbers of 2, 4, and 6. The materials of interest were Pyroceram 9606, reaction-sintered silicon nitride (RSSN), hot-pressed silicon nitride (HPSN), slip-cast fused silics (SCFS), and quartz polyimide (QPI). The mechanical analysis indicated that relatively thin ceramic radomes can withstand the assumed flight environments and that, when structural failure occurs, it may be due to either buckling or excessive bending moment stress at the base of the radome.

In the electrical performance investigation, a dual-band missile allowing 3 GHz passive guidance combined with 35 GHz terminal homing was assumed. For this concept an 0.078 in. halfwave Pyroceram radome was compared to full wave and half-sandwich designs. The electrical evaluation showed that the performance of the halfwave radome far exceeded that of the thicker alternatives. Its bandwidth was about 5 percent at 35 GHz compared to 2 percent for the others. Even within their passbands, the boresight errors of the full wave and half-sandwich will probably be twice those of the halfwave. However, although sturdy enough to survive a variety of missions, the halfwave radome is considered too fragile to survive the stresses of fabrication and military handling. If high frequency systems are to be used, methods must be found to allow the fabrication and handling of thin ceramic radomes.

RAIN DAMAGE PREDICTION

An effort is in progress to derive an expression for the amount of erosion occurring on a slip-cast fused silica radome flying at high speeds through rain. This information is needed to predict the changes in wall thickness and the resulting effects on the electromagnetic properties of the radome. An empirical expression for the maximum rate of erosion has been derived. The expression is based on results of tests by the U.S. Army Research and Development Command involving small samples of slip-cast fused silica radome material which are propelled through a controlled rain-field. These test data cannot be used to predict the variation of erosion in the axial direction because the samples tested were too short. Consequently, a purely theoretical approach is being used to predict axial variation in erosion. This involves modifications to the maximum erosion rate expression by the inclusion of several terms which vary as a function of the axial location on the radome.

Tests of full-size radomes will be conducted at the Rocket Sled Track at Holloman Air Force Base. The results of these tests will be used to verify the analytical formulas and modify them as necessary.

URLIM CODE MODIFICATIONS FOR IR DOME ANALYSIS

The Unified Radome Limitations (URLIM) computer program has been expanded to include a finite element thermal stress calculation technique. The new implementation of URLIM includes a slightly modified version of the SAAS III code for arbitrary axisymmetric or plane strain problems. The new code uses the SAAS software essentially as a subroutine under control of the URLIM main procedure. As such, the correlation of thermal mesh parameters with the finite element geometry definitions is accomplished automatically, with minimum additional input required. The code has been recently used to analyze an advanced IR dome concept for the Standard missile.

A further enhancement of the URLIM code for IR seeker analysis is under development, namely, prediction of the effects of an aerodynamically heated sensor window on a target acquisition range. This model integrates the radiant energy emitted by each finite element of the sensor window that reaches the IR detector. Combined with the detector characteristics, this model estimates when the signal-to-noise ratio for the target decreases below acceptable limits. The new result of the calculations is the variation of acquisition range during the missile's flight. A forthcoming user's guide for the improved version of the URLIM program will document these changes.

THERMAL AND RF VALIDATION OF THE SM-2 BLOCK II RADOME

The SM-2 Block II radome is predicted to experience wall temperatures up to 1300°F where substantial change in its RF performance can be noted. A radome design was developed that could perform acceptably when heated to the Block II temperatures. The design consists of an SM-2 Block I radome of Pyroceram 9606 with its wall thickness reduced by 0.003 in. and tuned with quartz tape at 75 MHz above the missile operating frequencies. A test program was carried out at the Department of Energy's Solar Facility in Albuquerque, New Mexico, to validate the RF performance of this new radome design at flight temperatures.

A total of 57 heated radome tests were completed during the program and the results revealed that all objectives were successfully met. Sufficient tests were performed at radome nose-area temperatures of 450°F, 800°F, and 1300°F to show that the off frequency tuning concept is satisfactory for the SM-2 Block II missile. In addition to tests of the new Block II radome, heated radome tests were conducted on a constant wall, unfortified radome to provide data for evaluating boresight error predictive methods. Data were gathered on this radome for temperatures up to 1500°F and it should prove valuable for use in evaluation of prediction codes.

Heated radome tests were also conducted on an SM-2 Block I radome at the Block II temperatures. The resulting boresight error data confirmed previous analytical predictions that excessive boresight error slopes would be experienced at high temperatures. These data showed conclusively that the SM-2 Block I radome is unacceptable for use on the Block II missile.

THERMAL AND RF RADOME TESTS FOR HYPERSONIC FLIGHT

A follow-on to the above program was carried out at the solar facility during March and April 1981. Tests were performed on four tuned and one constant wall untuned Pyroceram 9606 radomes and one untuned slip cast fused silica radome. Radome test temperatures extended from 800°F to 2200°F with accurate boresight error measurements being made on all tests. The general conclusions from this test program, which has not, as yet, been documented, is that the Pyroceram 9606 radome causes boresight error slopes of about twice the value considered acceptable when heated to temperatures of 1500°F and above. Also, the data showed the slip cast fused silica radome to be quite stable at temperatures up to 1900°F, and above that temperature its RF performance starts deteriorating rapidly. This work will be documented by the end of 1981.

VOUGHT CORPORATION
STRUCTURAL DYNAMICS AND LOADS

P.M. Kenner

MISSILE-LAUNCHER INTERACTION

Analyses and tests have been performed to identify design parameters most critical to missile tipoff. For the analytical work, a code was developed which includes missile and launcher flexibility in addition to large rigid body motion of the missile. Sabot and spin rail rider flexibility, concentricity, and clearances are also included. Tests were conducted for the Army MLRS and Quickshot Missiles and an in-house missile. Results obtained to date indicate that (1) simultaneous release of sabot and rider is superior to "dragging the tail" out of the tube, (2) smooth riding surfaces with minimum launch tube stiffness discontinuity are essential, (3) launch tube stiffness should be maximized, (4) launch tube-sabot clearances should be minimized, (5) breakout should be summetric, (6) tube length should be minimized.

Because thrust misalinment and blowby effects are extremely difficult to quantify, the contribution of missile-launcher interaction to total tipoff observed in flight data is never obvious. However, a Monte Carlo analysis including best estimates of all error sources is capable of yielding good design trades and tipoff predictions.

PENETRATION MECHANICS

Analyses and tests have been conducted to investigate the effectiveness of various penetrators against targets ranging from glass to four inch RHA. Tests for this in-house activity have been conducted at Socorro, New Mexico. The work was initiated to investigate the feasibility of using missile structure as a penetrator. This has the obvious advantage of reducing the weight of KE payload necessary for a kill. It was found that tubes require a higher velocity for penetration than rods of the same L/D and mass, and are more susceptible to obliquity. Conjecturing that only the first part of the tube was effective as a penetrator, a tubular enhancer was designed and tested with considerably more favorable results.

MISSILE ELEVON AEROELASTIC INSTABILITY

Catastrophic failure resulting from elevon flutter was experienced on a missile test flight although analysis and element impedance tests had indicated a margin at the critical condition. Subsequent investigation indicated that reduced impedance, from a buzz induced control system gas pressure drop, was a probable cause. A buzz induced piston failure was also suspected. The problem was resolved by increasing the flutter margin through mass balance and redesign of the piston. However, the onset of buzz was not predicted in the original linear analysis or by re-analysis using a nonlinear time domain technique. Known deficiencies in the analysis were hinge line rather than gap between main surface and control surface and a passive control system. Work is continuing in improved methods to predict the observed phenomena.

RAYTHEON COMPANY

D.H. Sanders

MOTOR IGNITION SHOCK SIMULATION

Motor ignition tests conducted on a new rocket motor at the Alleghany Ballistics Laboratory indicated high acceleration responses at the higher frequencies, 4 kHz to 10 kHz. Because responses at these frequencies have been proven to be of significant consequence to the performance of the new breed of sophisticated electronic devices and components, such environments must be simulated in the laboratory for engineering testing. Traditional methods of producing laboratory shock such as simple pulse drop testing and inputting transients through an electromagnetic shaker may fail to induce the required high frequency response necessary to simulate the ignition shock characteristics.

A return to the hammer impact test may be the only simple and expedient method of inducing the desired high frequency content of the ignition transient. The first hammer tests conducted to determine the feasibility of this type of testing to simulate the ignition shock were conducted by applying the hammer blow by hand. The results of these tests showed very good agreement between the hammer tests and the motor ignition tests in both the shock time histories (transient captures) and the derived shock response spectra.

This type of testing has the obvious flaw in that the impact level of the blow cannot be accurately predetermined nor controlled for test repeatability. A special pendulum hammer impact fixture was constructed which would deliver predictable and repeatable shock impacts. This fixture provided for adjustable pendulum length, variable hammer displacement, and interchangeable hammer masses. By manipulating these variables, hammer impacts can be delivered which produce the peak accelerations, transient time durations, and frequency content as portrayed by the shock response spectra to simulate the motor ignition shock transients. These tests are not only necessary to determine component performance in the shock environment but are also useful in tracing the shock transient characteristics through the structure and indicating possible means for providing additional shock attenuation for component protection.

ROCKET SLED ISOLATION SYSTEM

An isolation system was designed to protect experimental radomes from high vibration levels induced by rocket sleds during rain erosion tests at Holloman Air Force Base. The system had to attenuate radom power spectral density levels in the order of 20 G^2/Hz at track velocities up to 4500 ft/sec. An ideal design configuration would have been to mount the radome to a missile section and then isolate the section from the sled. This was not possible because the installation had to interface with an existing mounting ring on the sled which meant the radome had to be cantilevered off the isolation system. Hence a major design concern was to restrict a buildup of angle of attack which would cause the radome to diverge at high velocities.

The design was configured around Barry Controls Cupmounts as these mounts provided good snubbing action under high loads. Eight Cupmounts were arranged in a ring at the radome mounting base and provided attenuation of the high power spectral density levels which occurred at frequencies above 350 Hz of over 20 dB.

The maximum axial load at peak velocity was calculated to be 430 lb/mount and resulted in a radome angle of attack of less than 2 deg. Because the design loads on the mounts considerably exceeded their rated load, the mounts were tested in the laboratory to axial loads of 500 lb without any damage or change in the elastic characteristics. Due to the overload and high temperatures to which the mounts were subjected during a test run, the mounts were replaced after each run.

FACTORY SCREENING TESTS

Several years ago Raytheon conducted an industry-wide survey on limited environmental (factory screening) test procedures and submitted a report to the panel. Recent developments including increased sensitivity of electronic components to vibration and the necessity of isolating entire subsystems or systems has imposed increased difficulty in conducting adequate factory screening tests. Raytheon is currently reevaluating the factory screening test operations and attempting to update the procedures to effect more successful and reliable tests. Again it is anticipated that we must draw from the military and industrial community for inputs to such an effort.

PNEUMATIC CONTROL SYSTEM

Increasing interest in a penumatic control actuating system has led to studies to determine the stability and, hence, the feasibility of such systems. Flutter analyses were conducted using fin-body modes and parameters of control actuator stiffness and damping values. Studies to date indicate that it may be necessary to increase the actuator stiffness over what is normally achieved by this type of system, or by the introduction of auxiliary damping.

ISOLATION OF SMALL P.C. BOARDS

Due to the sensitivity of small electronic components, such as surface acoustic wave (SAW) devices and crystal oscillators, to vibration a study is in progress to develop new means of providing vibration protection to these types of components and the P.C. boards which become an integral part of the assembly. These efforts are complicated by the small mass and physical size of the assemblies which require the use of miniature elastomeric mounts and often by the requirements that the thermal and electrical continuity of the system cannot be adversely altered.

IMPACT TECHNOLOGY

Studies are in progress to define the elastic-plastic characteristics of projectiles on impact. Recent computer studies have produced time histories of the elastic-plastic deformations of projectiles and the impacted structure. Such studies should lead to a better understanding of both projectile and impacted structural design.

HONEYWELL INC., DEFENSE SYSTEMS DIVISION

S.N. Schwantes

DIE CAST FAE II BLU-96/B TAILCONE

In 1981, Honeywell took delivery of the first lot of 70 die cast aluminum tailcone housings for the FAE (fuel air explosive) II BLU-96/B, a 2000 lb class free fall weapon. The die cast aluminum (A380) housing replaces a similar permanent mold A356-T6 tailcone. While retaining the same material minimum strength properties, the die cast design is projected to result in a $47 million cost savings to the program for a production run of 100,000 weapons. At a weight of about 93 lb before final machining and a maximum height and diameter of 25.2 in. and 23.5 in., this is believed to be the largest aluminum die casting produced in the USA.

This process was developed under Task I of the FAE II BLU-96/B MM and T (manufacturing methods and technology) program conducted by Honeywell Inc. for PBM and the Naval Weapons Center, China Lake. During the coming year several die cast tailcones will be sectioned to obtain as-cast tensile test coupons. A static loads test will be conducted to verify that the required strength criteria have been met. Vibration testing is also planned on a completely assembled store.

ONE PIECE FAE II BLU-96/B SKIN

Task II of the previously mentioned MM and T program was to develop and fabricate a larger roll forming machine to allow the 10 ft long BLU-96/B dispenser fuel container skin section to be rolled as one piece. During previous phases of the FAE II program, the aluminum 6061-T6 fuel container skin was formed in three sections, requiring four extra circumferential welds and two aluminum weld rings to be used for assembly. For a 100,000 unit production run, the one-piece skin will save the program over $7.8 million and also eliminates the chance for fuel leaks in the four deleted weld zones.

Thirty longitudinal grooves are machined in the fuel container skin sections while still flat. This requires a specialized two-roll forming operation instead of the conventional three-roll method. A urethane coated roller plus a conventional steel roller with high line loads on the skin is used to roll the skin without excessive bending at each skin groove. The change to ten-ft rolls required the use of end moment loads to be applied to each roller to counteract roller bending deflections.

EPIC CODE IMPROVEMENTS

During 1980 and 1981, additional capabilities were added to the two-dimensional EPIC-2 code and the three-dimensional EPIC-3 code. These codes have been developed primarily for problems involving intense impulsive loading due to high velocity impact and explosive detonation. These codes are based on an explicit finite element formulation where the equations of motion are integrated directly without forming a stiffness matrix.

For intermediate rates of plastic deformation (strain rates), both heat generation and heat conduction can occur to offset work hardening effects. A heat-conduction option has been added to the EPIC codes to provide solutions for problems involving thermal-mechanical interaction. Other new improvements include an option to use a "coupled" Lagrangian-Eulerian computational technique and a three-dimensional anisotropic capability for wave propagation and plastic flow. This work has been funded by Honeywell ID programs and contracts with BRL and Eglin AFB.

LARGE STRAIN, HIGH STRAIN RATE TESTING OF METALS

During 1981, additional tests were run using a dynamic torsion testing machine developed for Honeywell Inc. by Southwest Research Institute. The hydraulic torsional testing machine is capable of continuous variation in strain rate from static up to approximately 500 s^{-1} and has sufficient torque capacity to fail high strength alloys used in armor or penetrators. These tests allow study of both strain hardening and thermal softening due to localized adiabatic heating at shear bonds in the metals. Metals studied so far include two aluminums (2024-T3 and 7039), four low alloy steels, two penetrator materials, and five high ductility materials (including OFHC copper and AISI 1006 steel). Materials currently undergoing testing include 4340 steel and nickel 201 plus repeat tests of some previous materials. The initial testing machine was developed with Honeywell ID funding. The Ballistic Research Laboratory has sponsored some testing and Eglin AFB is currently funding a contract to develop a fracture model for severe dynamic loading.

GENERAL DYNAMICS, POMONA DIVISION

W.H. Terrill

AIRFRAME MODAL TAILORING WITH COMPLIANT JOINTS

An airframe modal response problem developed in the late design phase of the RAM Anti Ship Missile Defense System due to a substantial reduction in the guidance section weight. The resulting aft shift in the forward node in the first bending mode - in combination with very low structural damping - increased the gain the autopilot accelerometer loop by 14 dB and created a potentially serious autopilot stability problem. Because the RAM missile is a derivative design using many components common to the Sidewinder missile (rocket motor, warhead, and target detection device), few structural changes were considered possible. Several modal response control options were considered and the use of a compliant joint between the guidance section and the control section was selected as the best choice. The compliance was introduced using elastomeric material bonded both to a bulkhead and a captive steel ring attached to the guidance shroud with shear screws. Stiffness tailoring was accomplished by controlling the durometer of the elastomer. By this means a 22 dB reduction in the accelerometer gain parameter was realized in combination with a sixfold increase in the first mode structural damping. Control test vehicle (CTV) flight results confirm the solution to autopilot-elastic mode stability and further show a dramatic reduction in the guidance section flight vibration environment.

COMPOSITE BOOSTER FIN DEVELOPMENT

A propulsion upgrade program for the Extended Range Standard Missile-2, has resulted in the development of a composite booster fin, to replace the cast magnesium fin used on earlier versions of the Standard and Terrier missiles. The composite fin design requirements in comparison to the magnesium booster fin, include: same planform, same or less weight, equal to or greater flutter and strength margins, and lower cost.

The composite fin design consists of an E260H glass reinforced epoxy molding and a hybrid outer shell. The outer shell is made of three layers of Kevlar, two layers of graphite, and three layers of Kevlar laid up on a rubber mandrel. The outer skin assembly is then cured in a mold cavity without an autoclave. The curing pressure is created by the thermal expansion of the rubber mandrel constrained in the mold cavity. The outer shell and the spar are bonded together as the final assembly step.

Both static and dynamic analysis of the composite fin were performed using the ANSYS code. A two-dimensional model was developed using 182 triangular elements and 112 nodes. A minimum margin of safety in excess of 1.5 was calculated for the maximum load condition in the static load analysis. For the dynamic analysis, the same model was used with 45 nodal displacements selected as master degrees of freedom. The lowest five of the resulting normal modes of vibration were then used in the Pomona Division supersonic flutter program to calculate the flutter speed. The predicted sea level flutter speed, ignoring heating above $M = 4.0$, is in excess of $M = 9.0$ as compared to $M = 6.0$ for the magnesium booster fin.

The prototype fins are being fabricated at this time and the design will be flight tested in early 1982 following preflight static and dynamic ground testing.

NEAR MISS SHIP SHOCK TESTING

As shipboard systems have grown in complexity, their ability to survive in shock environments has become increasingly marginal. In this regard a renewed interest in ship shock testing of new vessels has developed. One such vessel is the USS KIDD (DDG-993) which will undergo ship shock testing at levels up to two-thirds of the design shock factor. During these tests an instrumented SM-2 Block II dynamic inert missile (DIM) will be placed onboard the ship to measure the environment seen while on the ready service ring of the MK 26 Mod 0 missile launching system (GMLS).

The DIM will have twelve internal accelerometers which are located in sets of three in four of the major sections of the missile. These accelerometers will sense in the missile's vertical, horizontal, and longitudinal axes. Based upon a finite element transient response analysis, the missile reponses, when low passed at 100 Hz, are expected to be 15, 25, and 35 g's in the vertical, horizontal, and longitudinal directions, respectively. The rocket motor is instrumented with two rosetts strain gages near each shoe. The forward and more heavily loaded shoe is expected to induce strains in the range of 10,000 μin./in. in the maraging steel rocket motor. The aft shoe, which restricts the longitudinal or vertical motion in ships axes, will induce strains in the range of 2000 μin./in.

The instrumentation from the DIM is landlined to an onboard signal conditioning and recording system. This system has been mounted on a shock isolated instrument rack to withstand the ship shock environment.

MARTIN MARIETTA AEROSPACE
ORLANDO DIVISION

P.G. Hahn

HIGH PERFORMANCE, LIGHT WEIGHT MISSILE STRUCTURAL DYNAMICS

Dynamic loads present a challenge in the design of low altitude defense interceptors. Flyout performance and interceptor size require the use of a composite material such as high-modulus graphite, for the primary structure to achieve the required strength, stiffness, and weight. The critical structural design loads result from the pressures of nuclear blast flythrough. Also, the very rapid onset of these pressures, which are reinforced by the shock-on-shock pressures, cause a very severe shock environment for internal components. Another area of concern is the buckling stability of the composite shell structure when subjected to rapidly applied pressure pulses. In the test area, blast simulation techniques must be developed to verify the blast hardness of both the structure and internal equipment.

OPTICAL SEEKER SYSTEM STRUCTURAL DYNAMICS

Stabilized line of sight gimbal system requirements are becoming more demanding in areas of stabilization, environment, weight, and packaging. Dynamic analyses of these systems are crucial in aircraft and missile environments where vibration levels can be high, weight critical, and packaging constraints combined with folded optical paths lead to less than efficient load carrying structure. Techniques are being developed to analyze these complex structures to predict structural contributions to line of sight stabilization errors and optimize these structures, for minimum weight, to allowed deflection and frequency constraints. Results to date have shown a 25 percent analytical weight reduction with 10 percent actually realizable within the practical constraints of hardware.

STRUCTURAL RESPONSE TO X-RAY LOADING

The response of missile structures to nuclear x-ray loading has been of recent concern. It was feared that very detailed and complex shell models would be required to achieve acceptable results. However, it has been found that beam models with two shell harmonics included are able to account for 99 percent of the energy dispersion in the structure. This allows significant model simplification without degradation of results.

VERTICAL LAUNCHING SYSTEM STRUCTURAL DYNAMICS

Operational requirements of the shipboard missile vertical launching system have provided a new structural interface between missile and launcher. Both underwater blast survival and missile flyout have added a new spectrum of dynamic loads to be considered in missile structure and equipment design. Missile primary structure must contain hardpoints such as launch shoe supports and/or holdback fitting supports including safe and arm mechanisms. Constrained pressure loading of the structure must also be considered. In addition, launcher structure must be designed to aid in mitigation of shipboard loads transmitted to the ready missiles.

VOUGHT CORPORATION

C.M. Standard

METAL MATRIX COMPOSITES (MMC)

During 1981 Vought continued its IR and D contract activities in the evaluation and development of metal matrix composites. Vought internal research into MMC is directed at materials, component design and analysis, and fabrication and assembly considerations. Contract programs on MMC include (a) NSWC Contract N60921-81-C-0114 entitled "Application of Metal Matrix Composites to Tactical Missiles, Phase III;" (b) FDL Contract F33615-81-C-3211 entitled "Metal Matrix Composites Structural Demonstration for Missiles;" (c) continuation of FDL Contract F33615-80-C-3244 entitled "MMC for Advanced Airframes;" and (d) continuation of NASC Contract N00019-80-C-0643 entitled "Selective Reinforcement of Titanium Aerospace Structures." The work under these contracts is summarized briefly in the following paragraphs.

APPLICATION OF MMC TO TACTICAL MISSILES

The objective of this NSWC program is to design, fabricate, and qualify MMC missile components to the point of being ready for flight demonstration. The components being developed are a guidance bay (body shell structure) of silicon carbide particulate and aluminum, and a fin control surface made of a hybrid MMC construction using graphite and aluminum plies on a core of silicon carbide particulate and aluminum, and reinforced with plies of boron and aluminum.

MMC STRUCTURAL DEMONSTRATION

The technical objective of this FDL program is to demonstrate and validate the structural integrity, weight, cost, and other advantages of MMC materials when applied to full-scale structural demonstration missile components.

The program is currently in the first quarter (3 months) of the 40-month program. The attention of the program is presently focused on the selection of baseline components and the screening of candidate material systems.

MMC FOR ADVANCED AIRFRAMES

The objective of this FDL program is to generate basic design data for silicon carbide discontinuously reinforced aluminum MMC and to demonstrate the feasibility of efficient structural design based on the achievable material properties. The components being developed in this program include a missile fuel tank, a stiffened body shell structure, and a guidance system support structure.

The specific stiffness of this low cost MMC material provides a significant system payoff for these missile applications.

SELECTIVE REINFORCEMENT OF TITANIUM AEROSPACE STRUCTURES

The technical objective of this technology program for NASC is to evaluate the structural, material, and process characteristics and techniques for the selective reinforcement of titanium components using small or moderate quantities of titanium MMC reinforcements. Test results are showing significant strengthening and stiffening obtained by selective reinforcement. The effects are especially dramatic in bending applications.

VOUGHT IN-HOUSE MMC ACTIVITY

Vought has addressed the following subjects in its 1981 activities:

1. Characterization of MMC systems including particulate, whisker, and fiber composites

2. Failure criteria for MMC

3. NDE methodology for MMC

4. MMC fabrication techniques (machining, forming, fastening, etc.)

5. Missile system benefits (payoff studies)

SUPERPLASTIC FORMING AND DIFFUSION BONDING

Vought continued its efforts in SPF/DB during 1981 with significant achievements in two areas. These were:

1. The fabrication of a missile body section with an integrally formed flush inlet using the 7000 series aluminum. This SPF/DB part used the Vought-developed "expanded tube" technique.

2. The combination of SPF/DB of titanium with selective reinforcements of boron and titanium metal matrix composites.

GRUMMAN AEROSPACE CORPORATION

M. Bernstein

USE OF ADVANCED COMPOSITE MATERIAL IN THE DC-8 CFM-56 ENGINE NACELLE

The use of graphite bismaleimide composite material in place of conventional high temperature metal alloys in the anti-icing section of the DC-8 CFM-56 engine nacelle is expected to prevent sonic fatigue failures in this area. Past experience with jet aircraft engine nacelle inlet structures indicates that the acoustic environment has caused premature fatigue failures in metal components of the inlet anti-icing systems. Anti-icing in these inlets is accomplished by heating the leading edge portion of the inlet duct with high temperature engine bleed air forced through passages in the leading edge structure. This heating causes thermal stresses in the structure which, combined with the effects of the acoustic environment, causes fatigue cracks. In the CFM-56 nacelle the internal anti-ice flow deflector structure, which experiences temperatures up to 500°F and has previously been made of titanium or stainless steel alloys, has been fabricated of graphite bismaleimide composite. This material not only showed superior fatigue performance to titanium in an elevated temperature fatigue test, but also will experience lower thermal stress than its metallic counterpart because it has a lower coefficient of thermal expansion. A significant improvement in fatigue life of the anti-icing system is expected as a result of this application of advanced composites.

AUTOMATED SIZING OF A FORWARD SWEPT WING FOR STRENGTH AND DIVERGENCE REQUIREMENTS

A new computer program known at Grumman as FASTOP-4 was developed and applied to the preliminary design of the forward-swept wing of a demonstrator fighter presently being developed by Grumman for the USAF and DARPA. The program was used primarily to size the graphite and epoxy covers so as to achieve a divergence-free, strength-adequate design having near-minimum weight. The sizing process in the FASTOP series of programs is done at the finite-element level, thereby making the results more suitable for use in detailed design than those obtained by other methods which use beam or plate models to represent a lifting surface. Furthermore, the highly automated nature of the program allows for the rapid evaluation of various composite materials and fiber orientations for meeting strength and aeroelastic design requirements.

The FASTOP-4 program is the latest in a series of design and analysis tools which were developed originally under the sponsorship of the Air Force Flight Dynamics Laboratory and later expanded under Grumman's IRAD program. This latest version can treat static aeroelastic constraints on divergence speed, control-surface effectiveness, or flexible-surface lift-curve slope, in combination with strength requirements, with the same degree of automation that was previously available only for flutter-speed constraints. The procedures are highly oriented toward the least-weight design of surfaces having advanced-composite skins, although metallic construction can be treated just as well.

REDUCTION OF HYDRAULIC LINE OSCILLATING PRESSURES INDUCED BY PUMP CAVITATION

During the infrequent loss of aircraft hydraulic fluid during pump operation, cavitation has been induced leading to large oscillatory pressures. Tests on an hydraulic simulator representing the two independent aircraft hydraulic systems have shown that an Helmholtz resonator attenuator can be very effective in reducing the stresses induced in hydraulic lines and the brackets supporting them. This type of attenuator was selected because it did not interfere with pump operation or flow volume and it could be made quite compact. The unit is now being evaluated in an aircraft installation. The testing program was reinforced by development and application of a method for calculating standing pressure wave induced loads in finite element representation of hydraulic lines. This work will be described in the forthcoming 52nd Shock and Vibration Symposium.

ACCELERATION ENVIRONMENTAL TESTING OF FIBROUS COMPOSITES

A test program was conducted in which specimens were subjected to accelerated environmental conditions with and without accelerated fatigue. Some specimens were preconditioned to and maintained, if fatigue tested, at a specified moisture level (sequential conditioning). Others were loaded and conditioned simultaneously, starting dry and proceeding to a specified weight gain (concurrent conditioning). Still other specimens were started in a dry state and conditioned in a specified background equivalent humidity while mechanically loaded.

The results of accelerated tests (residual tension and compression) were evaluated using data obtained from real-time tests of 15-month duration, simulating aircraft storage at tropical and temperature locations and in the supersonic flight regime of the B-1 bomber. Comparisons of strength data from accelerated and real-time environmental tests indicate that specimens with the same final moisture contents have the same residual strengths, irrespective of the previous moisture history. Thus, if the end-of-life moisture level can be reached with schemes other than real-time testing, they will successfully duplicate the effects of real-time exposure. For the tropical environment and supersonic flight conditions, since real-time moisture levels are higher than those reachable by simple preconditioning, thermal spikes which exceed the glass transition temperature must be included in accelerated testing.

UNSTEADY TRANSONIC AERODYNAMICS

Although the transonic speed regime has long been recognized as the most critical for the majority of flutter and other aeroelastic phenomena, it has been only within the past few years that computers have become fast enough to consider the development of realistic unsteady-aerodynamic prediction methods in this area. For the most part, two types of computer codes have emerged from the work to date: (1) relatively economical methods for an important but limited range of parameters (e.g., low frequency); and (2) comprehensive but computationally very expensive methods that are useful primarily for benchmark calculations.

Development work at Grumman has attempted to strike a balance between these two types, and has focused on the finite-difference solution of the full-potential flow equations. As an important first step, an efficient alternating-direction-implicit algorithm in conservation form has been developed under a contract from the NASA Ames Research Center for the unsteady two-dimensional case. The method incorporates airfoil-adapted coordinate transformations, and correctly accounts for the speed, strength, and location of moving shock waves. Due to the coordinate transformations, the tangential-flow boundary condition can be correctly applied at the instantaneous airfoil-surface location.

CRITICAL CONFIGURATIONS FOR WING AND EXTERNAL-STORE FLUTTER

The large inventory of wing-mounted external stores carried by current attack aircraft makes it highly important that reliable, efficient methods be available for predicting critical configurations for wing and store flutter. The methods must be reliable in the sense of not "missing" any flutter-critical configurations from the many thousands that must be considered, and they must be efficient in terms of both calendar time and computer and/or wind-tunnel usage requirements. Unfortunately, the state of the art until recently has been such that wing and store flutter clearance has had to rely on a combination of engineering judgment and exhaustive analyses and/or tests of individual configurations, and thus efficiency and reliability could not be achieved simultaneously.

However, under a Grumman study for the Naval Air Systems Command, completed in 1980, it has been demonstrated that a new method using automated search techniques can provide a significant improvement over the current situation. The method uses derivatives of flutter velocity with respect to store properties to direct an efficient numerical search for the minimum flutter speed within a parameter space defined by the range of store properties at each store station. The method has been implemented in a pilot computer program and applied successfully to the A-6E aircraft and its extensive store inventory. A contract to provide program enhancements and to make the program available to Navy personnel via the Naval Air Development Center Central Computer System is now being initiated.

STRUCTURAL EVALUATION OF GR/BMI AT HIGH TEMPERATURES

This program will investigate the suitability of (GR/BMI) for structural application through static and fatigue testing of quasi-isotropic coupons and hat-stiffened shear panels at room temperature "dry" and high temperature "wet" conditions. This NADC sponsored work will include static testing of notched and smooth tension and compression coupons and horizontal shear specimens, fatigue testing at these coupons at constant amplitude and multiple levels (spectra), and static and fatigue testing of impacted coupons and hat-stiffened shear panels.

In addition, the temperature-dependent absorption characteristics of GR/BMI will be quantified in an early phase of the effort to permit accurate prediction of the expected in-service moisture contents and to enable adequate definition of the requisite conditioning and testing procedures for reliable simulation of these in-service conditions. The effects of a range of impact energy levels on GR/BMI will also be determined visually and ultrasonically in order to determine the level that causes barely visible impact damage for subsequent tests as a 'worst case' condition of subvisual damage.

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - ST. LOUIS

J. Schmich

HARPOON MISSILE CAPTIVE CARRY DYNAMIC ENVIRONMENTS
ON THE A-6E AIRCRAFT

The U.S. Navy's Harpoon anti-ship missile is a subsonic, air-breathing, cruise missile capable of being launched from a variety of surface ships, submarine, and aircraft. As part of the USN's effort to enhance current fleet usage, Harpoon is scheduled to be deployed on the A-6E Intruder attack aircraft. During the Harpoon/A-6E Integration Program recently completed, a series of flight tests were conducted using an instrumented test missile specifically designed to measure Harpoon captive carry dynamic environments. Twelve vibration and three acoustic measurements were taken at key locations along the length of the missile. Three flight configurations were flown during the captive carry tests. The first two configurations were with the Harpoon in the inboard and outboard A-6E wing store locations. The third configuration was with the Harpoon in the inboard location and a 300 gallon tank in the outboard location. Measurements were taken for a wide range of straight and level aircraft flight speeds and altitudes, and for a variety of aircraft maneuvers.

Overall vibration levels (GRMS), as well as power spectral density (PSD) distributions, were obtained for each vibration measurement. Comparisons of GRMS variations with missile station indicate that the response levels in the aft missile region, particularly in the lateral and vertical directions, are considerably greater in magnitude than for the forward section of the missile. The RMS levels in the forward portion are fairly uniform in both direction and location. This could well be attributed to the guidance section protruding ahead of the leading edge of the aircraft wing, where flow conditions would be expected to be less severe. In contrast, the high response near the missile aft end is probably the result of a more intense interaction flow field generated by the proximity of the missile with the aircraft wing and fuselage. For comparable flight dynamic pressure conditions, the data suggest that the trend is independent of test configurations.

A comparison of PSD plots for three measurement locations for a common flight condition shows the same variations noted with the GRMS levels. A comparison of aft missile region composite PSD plots for the inboard and outboard wing carry conditions was made to gain insight into the influence of wing station location on the Harpoon environment. The comparison indicates that spectral density levels are higher for the inboard captive carry configuration. Peak responses occur at similar frequencies for both inboard and outboard wing locations, indicating that the same system response modes are being excited, but with different intensity. A comparison of composite PSD plots associated with Harpoon measurements taken at the inboard station, with and without the external fuel tank, indicates that the presence of the adjacent store results in a reduction in spectral densities at some frequencies.

LAUNCHER GUIDE DEVELOPMENT PROGRAM STRUCTURAL DYNAMICS ANALYSIS

The U.S. Navy launcher guide development (LGDP) was initiated in September 1980. This program consists of designing and developing a new missile launcher guide to replace the existing (ASROC) guide. A guide is composed of two missile cells that stow and launch torpedoes, depth charges, and Harpoon missiles. There are four guides on an ASROC launcher, mounted in a parallel arrangement across the width of the launcher carriage. The new guide will be compatible with the existing launcher and will provide (1) increased flexibility to accommodate future missiles, (2) increased corrosion resistance, (3) increased survivability, (4) improved maintainability, (5) increased life, and (6) elimination of manual guide modifications for missile changeout.

Because this program is still in the design phase, the major structural dynamics effort has been involved with performing near-miss shock and harmonic response analyses to assure that the new guide will meet the requirements of MIL-S-901C shock and MIL-STD-167-1 vibration. Finite element dynamic models have been developed for the new guide, ASROC launcher carriage and floating shock platform (FSP) simulated ship deck. The dynamic model of the guide contains 1613 degrees-of-freedom (DOF). The ASROC carriage and FSP deck models are also fairly large and contain 1222 DOF and 882 DOF, respectively. The configurations of the new guide analyzed for near-miss shock were guide stowed and guide elevated 45 deg and 65 deg. As a result of these analyses, approximately 70 percent of the new guide structure had to be upgraded to withstand the near-miss shock environment. For the harmonic response analysis, the FSP deck model was removed. The MIL-STD-167-1 shipboard vibration (4 to 33 Hz) was applied at the ASROC carriage and ship deck interface. To date, only the guide stowed configuration has been analyzed. The analysis results have shown the structural responses to be well below those resulting from near-miss shock.

COMMON WEAPON CONTROL DYNAMIC ANALYSES

The common weapon control system (CWCS) contains the fire-control system for launching both the Harpoon antiship missile and the ship launched Cruise missile. The CWCS electronic equipment is contained within five large racks designed for operation on surface ships. The racks range in weight from 200 lb to 800 lb and measure approximately 4 ft × 3 ft × 2 ft. In order to protect the system from shipboard environments, the racks are supported by a set of six coiled, stainless steel isolators attached to the deck and bulkhead. Vendor data indicated that the isolators had a linear force displacement relationship only for small (<0.1 in.) deflections.

Finite element computer programs have long been used to determine response of structures to dynamic environments. The standard procedure for modeling the nonlinear load deflection relationship exhibited by most shock and vibration isolators is to use a linear "averaged" system stiffness. Simple elastic spring elements are available in most finite element packages and result in accurate analyses over a small range of deflections. However, over the range of large deflections, or where deflections are highly nonlinear, the linear elastic springs will yield erroneous results.

The NASTRAN finite element program was used to determine dynamic characteristics of the racks, including response to MIL-STD-167 vibration and MIL-S-901C shock environments. The cabinet was assumed to be rigid with all inertia properties lumped at its center of gravity (C.G.). The modal analysis was performed using spring values taken from the linear portion of the isolator force-deflection curve.

A linear stiffness was also used in the frequency response analysis, because only low amplitude accelerations were associated with the vibration environment. The shock environment, resulting from the medium weight shock machine, was expected to reach 120 g's, leading to large accelerations at the cabinet C.G. and large isolator deflections in the nonlinear range.

The first shock analysis was performed using the linear stiffness. Results indicated larger accelerations than expected. Using a complicated set of several NASTRAN cards, the nonlinear relationship was incorporated into the model which more realistically represented the true system. Results indicated significantly (~15 percent) reduced response accelerations and isolator deflections.

DYNAMIC CONSIDERATIONS FOR THE CRUISE MISSILE GUIDANCE SYSTEM DIGITAL SCENE MATCHING AREA CORRELATOR

McDonnell Douglas Astronautics Company has responsibility to put into production the Naval Avionics Center (NAC) developed Digital Scene Matching Area Correlator (DSMAC I) unit. The DSMAC is intended to be used on a cruise missile to improve missile accuracy just prior to target impact so that conventional weapons can be used. The production design was designated the DSMAC II. The missile attachment bolt pattern established by the DSMAC I is a three point attachment (one top and two side locations) in the plane of a missile station. Because the video camera in the DSMAC must look at the ground through a window in the missile shell, no fourth attachment at the bottom could be accommodated resulting in a cantilevered lower half of the unit. The DSMAC I was a prototype design and did not have to meet the environmental specifications that the DSMAC II was required to meet, therefore, this design was satisfactory. In addition, the DSMAC I design had equipment on either side of the attachment plate. As part of the production effort, all equipment was repackaged to fit on the forward side of the plate and the attachment plate was split into two overlying plates of combined thickness equal to the original. One of the plates served as an adapter plate that would accommodate varing missile attachment configurations, but with a standard bolt pattern so that the base plate could be overlaid on it. The initial design of the DSMAC II was predicted to have a first mode frequency of 90 Hz and transmissibility of 40. This was deemed unacceptable because of excessive deflection at the lower point of the cantilevered section and high deflections at the two side lugs and between boxes.

Design modifications to reduce these deflections were identified to be:

1. Addition of a fourth attachment point

2. Addition of a shear pin at lower attachment point

3. Increase in wall thickness

4. Addition of stiffening walls to the cantilevered lower plate

5. Addition of ribs to aft surface of base plate

6. Addition of gussets to the two side lugs

7. Replacement cf adapter plate/base plate with single plate

Evaluation of each of these modifications resulted in the implementation of only the last two. The others were discarded due to baseline missile constraints (forth attachment), ineffectiveness (shear pin), and violation of DSMAC packaging constraints (wall changes, base plate rib stiffeners). The final design first mode frequency was raised to 160 Hz with a transmissibility of 25 resulting in acceptable deflections for the baseline missile.

FLUTTER OF CONTROL SURFACES WITH STRUCTURAL NONLINEARITIES - PHASE II

The study was undertaken to extend methods to investigate control surface flutter with structural nonlinearities that were developed during the Phase I activity. The developed methods include the use of the describing function representation of structural nonlinearities associated with the control surface root rotational support structure. The major activities consisted of flutter solutions using improved aerodynamic representation and evaluation of limitations of the describing function analysis technique.

Flutter of a control surface having free play and preload nonlinearities in root roll and/or pitch degrees of freedom was investigated using unsteady incompressible aerodynamic theory. Flutter solutions were obtained for the "effective" physical system in which the nonlinear elements (root springs) were replaced with effective linear elements obtained using the describing function technique. Numerical time history solutions of the governing nonlinear equations of motion were obtained for correlation with flutter boundaries determined using the describing function approach. Limitations of the describing function technique were studied by including additional terms beyond the fundamental harmonic in the Fourier series expansion of the nonlinear spring's output wave shape. Magnitudes of these harmonics were compared with the magnitude of the fundamental harmonics for a range of control surface root spring rates and magnitudes of root spring nonlinearities. Combination of system parameters (support stiffness, nonlinearity magnitude, and motion amplitudes) were identified for which the higher harmonics of the Fourier series expansion are of importance. The accuracy critical combinations of system parameters are those for which the higher harmonics are large when compared to the fundamental component.

The conclusions of the study are: (1) unsteady aerodynamics are required to accurately predict nonlinear behavior at high reduced frequencies, (2) nonlinearities in pitch and roll produce a combined influence on system flutter response, (3) at low reduced frequencies, root pitch nonlinearities are more critical to system stability than are root roll nonlinearities, (4) numerical simulations indicate that the describing function approach is well-suited to flutter analysis with system nonlinearities, and (5) error analysis indicates that the inaccuracies introduced in the describing functional approach result from truncated higher harmonics.

STRUCTURES AND AEROELASTICITY PANEL RECOMMENDATIONS TO NAC

The following recommendations were generated by the panel during the meeting:

1. RECOMMENDATION:

Resolve the NASTRAN supersonic unsteady aeroelastic routines.

BACKGROUND:

Several panel members have had problems with the use of these routines.

a. The Naval Weapons Center is trying to correlate HARM data on predicted flutter boundaries with the outputs of NASTRAN using these routines.

b. General Dynamics, Pomona tried to use these routines for assault breaker tail fin flutter analysis giving erroneous results.

2. RECOMMENDATION:

Undertake a critical review of the current analysis and test procedures for designing shipboard equipment to withstand underwater shock.

BACKGROUND:

The MIL-S-901C, the design specification for shipboard equipment, calls for either a barge test or a hammer test to provide in the design, where equipment is too large for such tests or, where the Navy has allowed the contractor to prove in the design via analysis, the Dynamic Design Analysis Method (DDAM) procedure is specified. This analytical procedure is archaic and the accuracy questionable. Newer analytical techniques are becoming available (i.e., underwater shock analysis (USA code) that may be more appropriate to use.

Experience has shown that underwater shock requirements may design a major portion of a missile structure, and an over conservative analytical procedure will compromise the missile flight performance.

3. RECOMMENDATION:

Develop refractory structural materials required for inlets and combustors in hypersonic wide area defense missiles.

BACKGROUND:

Little work has been performed since 1968 to advance the state-of-the-art in this area. Studies of proposed advanced missiles indicate a need in the 2500°F to 3500°F for refractory metals and to 5000°F for oxidation resistant carbon-carbon materials.

4. RECOMMENDATION:

Perform evaluation and experimental verification of available store-in-the-presence-of-an aircraft airloads methods.

BACKGROUND:

Air launched missile designers need airloads to combine with inertia loads in compliance with MIL-A-8591 for structural design computerized methods have been developed fairly recently to fill this need. Although these methods are Navy sponsored and available for general use, their accuracy and limitations are not established, and in fact are questionable. Further effort, particularly verification with experimental data should be sponsored to define their range of applicability so that users in the Navy community can be confident of their results.

The original work or development of one of the codes was sponsored by NAVAIR but further work is needed to establish the range of applicability or limitations.

5. RECOMMENDATION:

Experimentally extract aerodynamic data and correlate with analytical methods.

BACKGROUND:

The Navy and Air Force for years have been integrating weapons on aircraft. The integration of these weapons has required that a flight flutter clearance be acquired either through in-house or contracted engineering efforts. The parts of a flutter analysis require that both the elastic and unsteady aerodynamic definition of the aircraft and weapons be engineered. The elastic responses of the aircraft with various weapons "on-board" are analytically defined, then verified by ground vibration tests (GVT). Confidence in the model is obtained through updates and modification to the aircraft and weapons' analytical vibration model based on the experimental results. There exist no such systematic analytical development and experimental verification in the area of unsteady aerodynamics. Yet these are the vital forcing functions of the flutter determinant which are of significant value in definition of dynamic instability of aircraft and weapons.

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APPENDIX A

NAVY AEROBALLISTICS COMMITTEE CHARTER

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
Washington, D. C. 20361
and
NAVAL SEA SYSTEMS COMMAND
Washington, D. C. 20362

IN REPLY REFER TO

NAVAIRINST 5420.8A
NAVSEAINST 5420.11
AIR 320C
SEA 03513
Ser 115
28 Jun 1975

NAVAIR INSTRUCTION 5420.8A
NAVSEA INSTRUCTION 5420.11

From: Commander, Naval Air Systems Command
Commander, Naval Sea Systems Command

Subj: Navy Aeroballistics Committee; establishment of

1. Purpose. To establish the Navy Aeroballistics Committee (NAC).

2. Cancellation. NAVAIR Instruction 5420.8 of 15 April 1967 and NAVORD Instruction 5420.8 of 15 April 1967 are superseded.

3. Definition. As used herein, "Aeroballistics" covers the following fields, in those phases pertinent to missiles and other naval weapons: fluid mechanics, flight dynamics and trajectory analysis, aeroelasticity and structural dynamics, internal aerodynamics, stability and control, and aerodynamic heating.

4. Responsibilities. This Committee shall be jointly responsible to the Commanders of the Naval Air Systems Command and the Naval Sea Systems Command and for administrative purposes shall report to the Assistant and Deputy Commanders for Research and Technology. It will function in an advisory capacity in the field of aeroballistics to the two Commands. The Committee shall be responsible for:

a. Promoting the exchange of information among naval activities, contractors to the two Commands, and other agencies engaged in aeroballistic work with regard to the technological state-of-the-art, discoveries and inventions, other new developments, theories and techniques, new requirements and facilities, and problem areas requiring additional research.

b. Reviewing annually, or more frequently if deemed necessary, the current and projected Navy research and development effort in aeroballistics; identify work not being supported, and make recommendations jointly to the two Systems Commands for the support of important and/or critical work areas; and additionally, to point out any unwarranted duplication of research efforts.

c. Indicating needs, reviewing plans, and making recommendations for new or improved facilities and testing techniques required to maintain the Naval Air and Naval Sea Systems Commands' aeroballistics research and development at a high level.

d. Providing an annual report, or special reports as required, on the above responsibilities to the Commanders of the Naval Air and the Naval Sea Systems Commands.

5. Authority. The Committee is authorized to receive all technical information on any of the aeroballistic phases of research and development from activities connected with the Department of Defense engaged in such work. Release of reports of this Committee to activities or individuals outside the Naval Material Command shall require approval by the Assistant and Deputy Commanders of the Research and Technology Groups of the Naval Air and the Naval Sea Systems Commands. The Committee is authorized to set up panels and appoint members thereto to assist it in carrying out its assigned functions. The Committee is also authorized such other liaison as may be required to carry out its charged responsibilities.

6. Membership

a. Membership of this Committee shall be comprised of members, alternates, and associate members. One member and one alternate shall be appointed as of 1 January each year to the Committee by the Commander of the Naval Surface Weapons Center; Naval Weapons Center; Pacific Missile Test Center; Naval Ship Research and Development Center, Department of Aerodynamics; Naval Air Development Center; and by the Director of the Applied Physics Laboratory (JHU). Other naval activities engaged in major aeroballistics research and development programs may be designated for membership by joint action of the Naval Air and the Naval Sea Systems Commands.

b. Associate members shall be appointed by the Commanders of the Naval Air and Naval Sea Systems Commands as of January each year to represent the Systems Command offices engaged in aeroballistics research and development. Associate members shall not be entitled to vote but will be responsible for the maintenance of direct liaison between their organizations and the Committee.

c. A Chairman will be elected by and from among the voting members of the Committee to serve a period of one year.

d. The Committee shall recommend annually, to the Commanders of the Naval Air and the Naval Sea Systems Commands, an associate member to act as an executive secretary and as the principal liaison between the Committee and the two Systems Commands for that year. The executive secretary will be responsible for the maintenance of a decentralized official file containing complete information concerning the activities of NAC, including specifically: agenda, transcripts or notes of meetings, reports or other data, and compilations or working papers made available to, or prepared by or for, the Committee. These records will be permanent Navy records in accordance with SECNAVINST P5212.5B, paragraph 5420(1)(a).

The executive secretary will inform the Committee of Systems Commands requests for review of facility plans and research proposals and make arrangements for meetings that may be required between him, the Chairman, the Commanders, or the Assistant and Deputy Commanders for Research and Technology of the Naval Air and the Naval Sea Systems Commands to discuss the annual NAC report or other matters needing mutual Naval Air and Naval Sea Systems Commands and Committee's consideration.

7. Organization and Procedures

a. Each member shall be entitled to one vote. In a member's absence, his alternate may vote in his stead. Three quarters of the voting members shall constitute a quorum. No decision shall be made involving specific interests of any member activity in the absence of its voting member. In such a case, the question will be placed on the agenda for the next meeting and acted upon whether or not the activity involved is then represented. In the event any vote is not unanimous, the dissenting members may at their discretion submit a minority report for review and consideration by the Assistant and Deputy Commanders for Research and Technology of the Naval Air and the Naval Sea Systems Commands.

b. The Committee shall establish technical panels to aid and support its work in various areas of specialized interest. These panels are established by vote of the Committee and are continued until the Committee disestablishes the panel or changes its mission. The panels will be composed of members from the interested Navy laboratories, Systems Command Offices, and contractors to the above. Nominations to the panels may be made by any member or associate member of the Committee and the appointments made by the Committee Chairman. Before making the appointments, the Chairman will obtain concurrence of the nominee and his agency. The appointments will be made for a period of one year starting January 1. Appointments of non-governmental panel members will be terminated when the contract, which was the basis for their appointment, is completed. The Committee selects the Chairmen of the panels.

c. The Committee shall meet annually concurrently with its panels to review progress, new requirements, and facility plans. Each panel and each facility will submit a report at this meeting. Following the meeting, a report will be prepared and submitted by the Committee to the Naval Air Systems Command and the Naval Sea Systems Command, summarizing developments and listing items of significant progress, critical and important areas in aeroballistics research and development, and the needs for new or improved facilities. Other meetings may be convened by the Chairman and special reports issued to the Systems Commands as appropriate.

d. The Committee shall also sponsor technical symposia for promoting the exchange of information in aeroballistic research. The symposia will have a broader attendance base than the naval laboratories and their contractors. They will be open to the other military services and government agencies, such as NASA and AEC, and contractors to these with special competence in aeroballistics. Invitations to these symposia will be tendered by the Commanders of the Naval Air and Naval Sea Systems Commands. These symposia usually will be held at three-year intervals.

R. C. GOODING
Commander
Naval Sea Systems Command

K. L. LEE
Commander
Naval Air Systems Command

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APPENDIX B

CHARTERS OF THE PANELS OF THE NAVY AEROBALLISTICS COMMITTEE

CHARTER OF THE NAC
AIR INLETS AND DIFFUSERS PANEL

PURPOSE

The purpose of this panel shall be to review and evaluate technical progress in the field of air inlets and diffusers being carried out under the cognizance of the Naval Air and the Naval Sea Systems Commands, exchange information, and make recommendations to the Committee concerning the promotion and direction of research in this field. This shall include coordination with other panels appointed by the Committee where common interest exists and the correlation of the work of the Naval Air and the Naval Sea Systems Commands with related work conducted by facilities not under the Commands.

SCOPE

The NAC panel on Air Inlets and Diffusers shall concern itself mainly with studies on the magnitude and quality of pressure recovery, the mass flow capture, and the total drag of air inlets and diffusers. These studies will include effects of boundary layer, angle of attack, Mach number, and the interactions with other vehicle components. The panel will also be concerned with the performance of diffusers in wind-tunnel circuits, thrust augmenting ejectors, and in the internal flow systems in high energy laser devices.

MEMBERSHIP AND MEETINGS

The panel members shall be appointed by the NAC chairman from nominations by the Committee and shall meet once each year concurrently with the meeting of the Committee as scheduled by the Committee chairman. The panel shall submit an annual report to the Committee during this meeting. The panel chairman may schedule other meetings of the panel.

CHARTER OF THE NAC
GAS DYNAMICS PANEL

PURPOSE

The purpose of this panel shall be to review and evaluate technical progress in the field of gas dynamics being carried out under the cognizance of the Naval Air and Naval Sea Systems Commands, exchange information, and make recommendations to the Committee concerning the promotion and direction of research in this field. This shall include coordination with other panels appointed by the Committee where common interest exists and the correlation of the work of the Naval Air and Naval Sea Systems Commands with similar work conducted by facilities not under the Commands.

SCOPE

The NAC panel on Gas Dynamics shall concern itself, in general, with the fundamental fluid mechanics and gas dynamics of flow that occur in and around or are related to guided and unguided missiles and projectiles. The panel shall consider work which is devoted to the basic understanding of and the ability to predict detailed flow-field structure. Examples are as follows:

1. Attached flow fields which are complex enough to require special experimental or analytical tools to determine their details, e.g., computational techniques which impact on missile and projectile design technology.

2. Separated flows such as occur near control surfaces, on vehicles at an angle of attack, in wakes, and in diffusers.

3. High temperature gas dynamic problems including the effects of molecular excitation, chemistry, and radiation.

4. Boundary-layer and shock-wave behavior including the entire region between continuum and free-molecular flow.

5. Boundary-layer stability and turbulence.

6. Special problems relating to internal fluid mechanics of solid and liquid propellent guns and propulsion devices.

7. The panel will also be concerned with the latest test facilities and testing techniques as they pertain to aeroballistics.

MEMBERSHIP AND MEETINGS

The panel membership shall be appointed by the NAC chairman from nominations by the Committee and shall meet once each year concurrently with the meeting of the Committee as scheduled by the Committee chairman. The panel shall submit an annual report to the Committee during this meeting. The panel chairman may schedule other meetings of the panel.

CHARTER OF THE NAC
HEAT TRANSFER PANEL

PURPOSE

The purpose of this panel shall be to review and evaluate technical progress in the field of heat transfer viscous effects, material thermal response, and erosion being carried out under the cognizance of the Naval Air and Naval Sea Systems Commands, exchange information, and make recommendations to the Committee concerning the promotion and direction of research in this field. This shall include coordination with other panels appointed by the Committee where common interest exists and the correlation of the work of the Naval Air and the Naval Sea Systems Commands with related work conducted by the facilities not under the Commands.

SCOPE

The NAC panel on Heat Transfer shall be concerned with all modes of heat transfer (conduction, convection, and radiation), its ffects on structures and thermal protection materials, the interaction between heat transfer and other flow field characteristics, and the thermal properties of materials. Because both heat transfer and skin friction are extremely sensitive to the type of flow in the boundary layer, transition from laminar to turbulent flow will also be of prime interest. In addition to these main topics, the panel shall be concerned with such related topics as fluid injection, ablation, and other methods of controlling temperature. Boundary layer characteristics, in general, and their relation to base flow phenomena (particularly base drag and base heating) will be of interest. Erosion of components of flight vehicles traversing rain, ice, and dust environments shall also be considered by this panel.

MEMBERSHIP AND MEETINGS

The panel members shall be appointed by the NAC chairman from nominations by the Committee and shall meet once each year concurrently with the meeting of the Committee as scheduled by the Committee chairman. The panel shall submit an annual report to the Committee during this meeting. The panel chairman may schedule other meetings of the panel.

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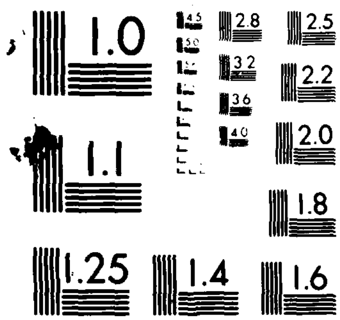

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CHARTER OF THE NAC LAUNCH DYNAMICS PANEL

PURPOSE

The purpose of this panel shall be to review and evaluate technical progress in the field of separation of stores from aircraft as well as the launch of missiles or projectiles from other vehicles under the cognizance of the Naval Air and the Naval Sea Systems Commands, exchange information, and make recommendations to the Committee concerning the promotion and direction of research in this field. This shall include coordination with other panels appointed by the Committee where common interest exists and the correlation of the work of the Naval Air and the Naval Sea Systems Commands with related work conducted by facilities not under the Commands.

SCOPE

The NAC panel on Launch Dynamics shall concern itself with aerodynamic loads and moments on all types of externally and internally carried airborne stores and bodies carried by other vehicles either captive or during separation; with the mutual interaction between the body and its carrier including associated racks and pylons; and with separation and recovery dynamics and trajectories. The panel shall also concern itself with the integration of the overall characteristics of a complete weapons delivery system including the carrier as a stable platform and mounting and ejection systems insofar as they relate to the expeditious handling and accurate delivery of the weapon.

MEMBERSHIP AND MEETINGS

The panel members shall be appointed by the NAC chairman from nominations by the Committee and shall meet once each year concurrently with the meeting of the Committee as scheduled by the Committee chairman. The panel shall submit an annual report to the Committee during this meeting. The panel chairman may schedule other meetings of the panel.

CHARTER OF THE NAC
MISSILE STABILITY AND PERFORMANCE PANEL

PURPOSE

The purpose of this panel shall be to review and evaluate technical progress in the field of missile stability and performance being carried out under the cognizance of the Naval Air and the Naval Sea Systems Commands, exchange information, and make recommendations to the Committee concerning the promotion and direction of research in this field. This shall include coordination with other panels appointed by the Committee where common interest exists and the correlation of the work of the Naval Air and the Naval Sea Systems Commands with related work conducted by facilities not under the Commands.

SCOPE

The NAC panel on Missile Stability and Performance shall concern itself with longitudinal and lateral stability and control characteristics of guided missiles, static and dynamic stability of unguided missiles, and the means of improving these characteristics. The areas of interest shall include research on all aerodynamic component interactions, autopilot input-output characteristics, together with jet, aero-thermoelastic, and other responses of the missile insofar as they affect system stability. The panel will also consider the interaction of aerodynamic forces (including thrust and drag) and moments on the maneuverability and trajectory characteristics of the missile.

MEMBERSHIP AND MEETINGS

The panel members shall be appointed by the NAC chairman from nominations by the Committee and shall meet once each year concurrently with the meeting of the Committee as scheduled by the Committee chairman. The panel shall submit an annual report to the Committee during this meeting. The panel chairman may schedule other meetings of the panel.

CHARTER OF THE NAC
STRUCTURES AND AEROELASTICITY PANEL

PURPOSE

The purpose of this panel shall be to review and evaluate technical progress in the field of structures and aeroelasticity being carried out under the cognizance of the Naval Air and the Naval Sea Systems Commands, exchange information, and make recommendations to the Committee concerning the promotion and direction of research in this field. This shall include coordination with other panels appointed by the Committee where common interest exists and the correlation of the work of the Naval Air and the Naval Sea Systems Commands with related work conducted by the facilities not under the Commands.

SCOPE

The NAC panel on Structures and Aeroelasticity shall concern itself mainly with problems of the structural design environment and structural applications of materials including: strength and stiffness, self-excited or sustained vibration, distribution of airloads, structural response, and aerodynamic stability and control in which the deformation of the structure is a factor. In general, these problems arise from interaction between aerodynamic forces, structural restoring forces, servo control forces, inertial forces, aerodynamic heating, and the vehicle airframe. These various interactions can lead to specific actions such as:

1. Flutter
2. Divergence
3. Missile instability
4. Control ineffectiveness
5. Structural vibration
6. Fatigue
7. Structural failure

MEMBERSHIP AND MEETINGS

The panel members shall be appointed by the NAC chairman from nominations by the Committee and shall meet once each year concurrently with the meeting of the Committee as scheduled by the Committee chairman. The panel shall submit an annual report to the Committee during this meeting. The panel chairman may schedule other meetings of the panel.

APPENDIX C

MEMBERSHIP OF THE COMMITTEE

NAVY AEROBALLISTICS COMMITTEE

MEMBERS AND ALTERNATE MEMBERS FOR 1981

S. de los Santos, Chairman (DTNSRDC)	A.E. Johnson
L.L. Cronvich (JHU/APL)	E.T. Marley
C. de Crescente (NADC)	E.J. McQuillen
L.H. Schindel (NSWC)	F.G. Moore
W.J.H. Smithey (PMTC)	W.L. Miller
R.W. Van Aken (NWC)	L. Smith

ASSOCIATES

L. Pasiuk, Executive Secretary (NAVSEASYSCOM)
W.E. Volz (NAVAIRSYSCOM)
G.S. Pick (NAVSEASYSCOM)
F.S. Pierce (NAVAIRSYSCOM)

NAC PANELS AND PANEL CHAIRMAN FOR 1981

Air Inlets and Diffusers	T.C. Tai (DTNSRDC)
Gas Dynamics	W.H. Clark (NWC)
Heat Transfer	T.F. Zien (NSWC)
Launch Dynamics	K. Okauchi (NWC)
Missile Stability and Performance	T.R. Pepitone (NSWC)
Structures and Aeroelasticity	A.A. Anderson (PMTC)

APPENDIX D

PAST CHAIRMEN OF THE NAVY AEROBALLISTICS COMMITTEE

PAST NAC CHAIRMEN

Feb 1949 - Nov 1949	CDR H.M. Mott-Smith (BuOrd)
Dec 1949 - Oct 1950	CDR L.G. Pooler (BuOrd)
Oct 1950 - Feb 1953	CDR L.G. Pooler (NOL)
Mar 1953 - Jul 1953	A.I. Moskovits (Acting) (BuOrd)
Sep 1953 - Jul 1955	E.A. Bonney (JHU/APL)
Aug 1955 - Aug 1957	H.H. Kurtzweg (NOL)
Sep 1957 - Jul 1959	W.R. Haseltine (NWC)
Aug 1959 - Jul 1961	R.A. Niemann (NSWC/DL)
Jul 1961 - Jan 1963	R.E. Wilson (NOL)
Jan 1963 - Jan 1965	S.T. de los Santos (DTNSRDC)
Jan 1965 - Jan 1967	R.H. Peterson (NMC)
Jan 1967 - Jan 1969	W.A. Kemper (NSWC/DL)
Jan 1969 - Jan 1971	L.L. Cronvich (JHU/APL)
Jan 1971 - Jan 1973	W.R. Haseltine (NWC)
Jan 1973 - Jan 1975	R.E. Wilson (NSWC/WOL)
Jan 1975 - Jan 1976	S.T. de los Santos (DTNSRDC)
Jan 1976 - Jan 1977	J.W. Rom (PMTC)
Jan 1977 - Jan 1978	W.A. Langen (NADC)
Jan 1978 - Jan 1979	R.W. Van Aken (NWC)
Jan 1979 - Jan 1980	L.L. Cronvich (JHU/APL)
Jan 1980 - Jan 1981	L.H. Schindel (NSWC)
Jan 1981 -	S.T. de los Santos (DTNSRDC)

APPENDIX E

MEETINGS OF THE COMMITTEE

MEETINGS OF THE COMMITTEES

Meeting	Date	Location
	(Bureau of Ordnance Committee on Aerodynamics)	
1	1 Feb 1949	Navy Department, Washington, D. C.
2	26 May 1949	Naval Ordnance Laboratory White Oak, Md.
	(Bureau of Ordnance Committee on Aeroballistics)	
3	5 Jul 1949	Naval Ordnance Laboratory White Oak, Md.
4	12-13 Sep 1949	Naval Supersonic Laboratory Massachusetts Institute of Technology
5	7-8 Dec 1949	Naval Weapons Laboratory Dahlgren, Va.
6	3-4 Mar 1950	Naval Weapons Center China Lake, Calif.
7	10-11 May 1950	Ordnance Aerophysics Laboratory Daingerfield, Texas
8	27-28 Jul 1950	Naval Weapons Center China Lake, Calif.
9	9-10 Oct 1950	Naval Ordnance Laboratory White Oak, Md.
10	25-26 Jan 1951	Naval Supersonic Laboratory Massachusetts Institute of Technology
11	9-10 Apr 1951	Naval Weapons Center China Lake, Calif.
12	19-20 Jul 1951	Naval Weapons Laboratory Dahlgren, Va.
13	29-30 Nov 1951	Ordnance Aerophysics Laboratory Daingerfield, Texas
14	27-28 Feb 1952	Johns Hopkins University Applied Physics Laboratory Silver Spring, Md.

MEETINGS OF THE COMMITTEES (Continued)

Meeting	Date	Location
	(Bureau of Ordnance Committee on Aeroballistics)	
15	16 May 1952	Naval Weapons Center China Lake, Calif.
16	15 Jul 1952	National Aeronautics and Space Administration, Ames Research Center
17	19-20 Nov 1952	Naval Weapons Laboratory Dahlgren, Va.
18	9-10 Apr 1952	Naval Supersonic Laboratory Massachusetts Institute of Technology
19	13-14 Jul 1953	General Dynamics, Pomona Division
20	28-29 Oct 1953	Naval Ordnance Laboratory White Oak, Md.
21	11-12 Feb 1954	Johns Hopkins University Applied Physics Laboratory Silver Spring, Md.
22	13-14 May 1954	Arnold Engineering Development Center Arnold Air Force Station, Tenn.
23	21-22 Oct 1954	Johns Hopkins University Applied Physics Laboratory Silver Spring, Md.
24	16-18 Jan 1955	Naval Ordnance Laboratory White Oak, Md.
25	31 Jan - 1 Feb 1956	Naval Ordnance Laboratory White Oak, Md.
26	31 Jan - 1 Feb 1957	Naval Ordnance Laboratory White Oak, Md.
27	21-24 Jan 1958	Naval Ordnance Laboratory White Oak, Md.
28	2-6 Feb 1959	Naval Ordnance Laboratory White Oak, Md.

MEETINGS OF THE COMMITTEES (Continued)

Meeting	Date	Location
	(Bureau of Weapons Advisory Committee on Aeroballistics)	
29	19-22 Jan 1960	Naval Ordnance Laboratory White Oak, Md.
30	14-17 Feb 1961	Naval Ordnance Laboratory Point Mugu, Calif.
31	29 Nov - 1 Dec 1961	Naval Ordnance Laboratory White Oak, Md.
32	6-9 Nov 1962	Johns Hopkins University Applied Physics Laboratory Silver Spring, Md.
33	4-6 Nov 1963	Naval Ship Research and Development Center, Bethesda, Md.
34	6-8 Oct 1964	Naval Weapons Center China Lake, Calif.
35	21-23 Sep 1965	Naval Ordnance Laboratory White Oak, Md.
36	4-6 Oct 1966	Johns Hopkins University Applied Physics Laboratory Silver Spring, Md.
	(Navy Aeroballistics Advisory Committee)	
37	10-13 Oct 1967	Naval Weapons Laboratory Dahlgren, Va.
38	8-11 Oct 1968	Naval Missile Center Point Mugu, Calif.
39	7-9 Oct 1969	Naval Ship Research and Development Center, Bethesda, Md.
40	27-29 Oct 1970	Naval Weapons Center China Lake, Calif.
41	12-15 Oct 1971	Naval Ordnance Laboratory White Oak, Md.
42	19-22 Sep 1972	Naval Weapons Laboratory Dahlgren, Va.

MEETINGS OF THE COMMITTEES (Continued)

Meeting	Date	Location
		(Navy Aeroballistics Advisory Committee)
43	1-4 Oct 1973	Johns Hopkins University Applied Physics Laboratory Silver Spring, Md.
44	7-10 Oct 1974	Naval Surface Weapons Center White Oak, Md.
45	7-9 Oct 1975	David W. Taylor Naval Ship Research and Development Center Bethesda, Md.
46	28-30 Sep 1976	Pacific Missile Test Center Point Mugu, Calif.
47	18-21 Oct 1977	Naval Air Development Center Warminster, Pa.
48	16-19 Oct 1978	Naval Weapons Center China Lake Calif.
49	16-18 Oct 1979	Johns Hopkins University Applied Physics Laboratory Laurel, Md.
50	6-9 Oct 1980	Naval Surface Weapons Center White Oak, Md.
51	5-8 Oct 1981	David W. Taylor Naval Ship Research and Development Center Bethesda, Md.

AEROBALLISTICS FACILITIES REVIEW MEETINGS

Meeting	Date	Location
1	20-22 Mar 1962	David W. Taylor Naval Ship Research and Development Center Bethesda, Md.
2	20-21 Apr 1965	Naval Weapons Laboratory Dahlgren, Va.
3	12-13 Jun 1967	David W. Taylor Naval Ship Research and Development Center Bethesda, Md.

APPENDIX F

NAVY SYMPOSIA ON AEROBALLISTICS

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U.S. NAVY SYMPOSIUM ON AEROBALLISTICS

FIRST SYMPOSIUM - NOVEMBER 1950
Hosted by . . . . Defense Research Laboratory
Held at . . . . University of Texas, Austin, Texas

SECOND SYMPOSIUM - MAY 1952
Hosted by . . . . Naval Weapons Center
Held by . . . . Huntington Hotel, Pasadena, Calif.

THIRD SYMPOSIUM - OCTOBER 1954
Hosted by . . . . The Johns Hopkins University, Applied Physics Laboratory
Held at . . . . The Johns Hopkins University, Applied Physics Laboratory
Silver Spring (Howard County Location), Md.

FOURTH SYMPOSIUM - NOVEMBER 1957
Hosted by . . . . Naval Weapons Laboratory
Held at . . . . Department of Commerce Auditorium, Washington, D.C.

FIFTH SYMPOSIUM - OCTOBER 1961
Hosted by . . . . Naval Ordnance Laboratory
Held at . . . . Naval Ordnance Laboratory, White Oak, Md.

SIXTH SYMPOSIUM - OCTOBER-NOVEMBER 1963
Hosted by . . . . Naval Ship Reearch and Development Center
Held at . . . . National War College, Fort McNair, Washington, D.C.

SEVENTH SYMPOSIUM - JUNE 1966
Hosted by . . . . Naval Missile Center
Held at . . . . Naval Missile Center, Point Mugu, Calif.

EIGHTH SYMPOSIUM - MAY 1969
Hosted by . . . . Naval Weapons Center
Held at . . . . NWC Corona Laboratories, Corona, Calif.

NINTH SYMPOSIUM - MAY 1972
Hosted by . . . . The Johns Hopkins University, Applied Physics Laboratory
Held at . . . . The Johns Hopkins University, Applied Physics Laboratory
Silver Spring (Howard County Location), Md.

TENTH SYMPOSIUM - JULY 1975
Hosted by . . . . Naval Surface Weapons Center, Dahlgren, Virginia
Held at . . . . Sheraton Fredericksburg Motor Inn, Fredericksburg, Va.

ELEVENTH SYMPOSIUM - AUGUST 1978
Hosted by . . . . Naval Air Development Center, Warminster, Pa.
Held at . . . . Hilton Northeast Philadelphia, Trevose, Pa.

TWELFTH SYMPOSIUM - MAY 1981
Hosted by . . . . David W. Taylor Naval Ship Research and Development Center
Held at . . . . David W. Taylor Naval Ship Research and Development Center
Carderock, Md.

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